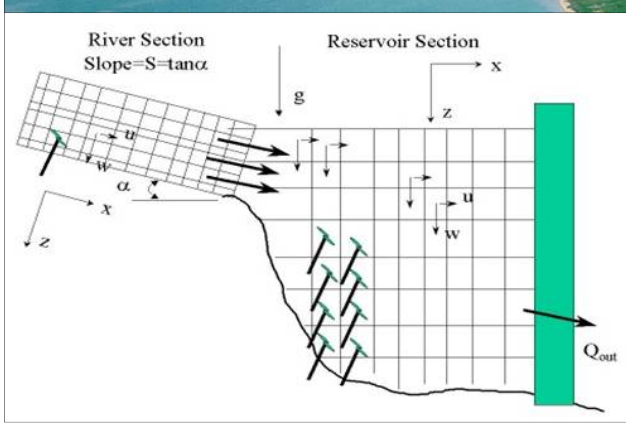
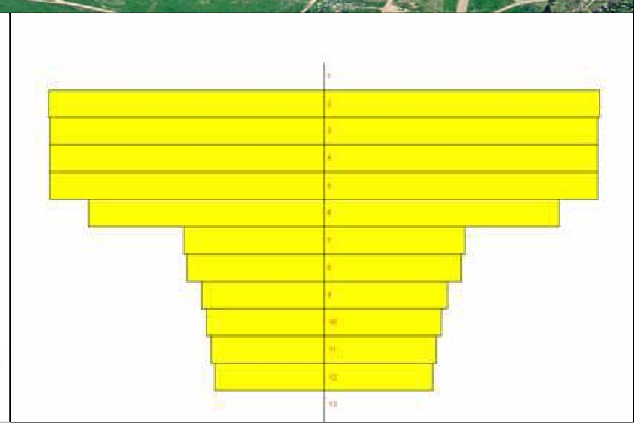
Water Quality Modeling Report

U.S. Army Corps of Engineers
Omaha District

Application of the CE-QUAL-W2 Hydrodynamic and Water Quality Model to Fort Peck Reservoir, Montana





Aerial Photo of Fort Peck Dam, Tailwaters and Lake

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Application of the CE-QUAL-W2 Hydrodynamic and Water Quality Model to Fort Peck Reservoir, Montana

(Report Number: CENWO-ED-HA/WQMR/Fort Peck/2009)

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EXECUTIVE SUMMARY

The District developed a CE-QUAL-W2 water quality model for Fort Peck Lake after the completion of the three-year intensive water quality survey to assess water quality conditions and coldwater habitat volume in the reservoir. The reservoir model was configured to compute temperature, dissolved oxygen, and organic nutrients using semi-deterministic algorithms, and it was calibrated to 2004 through 2006 water temperature and dissolved oxygen measurements from the intensive water quality survey period, and in 2007 and 2008. Additional simulations evaluated the effectiveness of releasing warmer water from a hypothetical high-level reservoir withdrawal to the Missouri River for pallid sturgeon habitat enhancement downstream of Fort Peck Dam. The calibrated model predicted temperature in degrees Celsius and dissolved oxygen concentrations in milligrams per liter (mg/L) in the reservoir with root mean square errors of 1.02 and 0.57, respectively. The model predicted reservoir discharge temperature and dissolved oxygen concentrations with root mean square errors of 1.01 and 1.80, respectively.

Predicted discharge temperatures from the existing Fort Peck outlet peaked between 17^{o}C and 18.5^{o}C from 2004 through 2007, while in 2008, the year of the highest average pool elevation, predicted discharge temperature peaked near 16.5^{o}C. These model results suggest low pool elevations yield warmer discharge temperatures, while high pool elevations yield cooler discharge temperatures. Ambient air temperatures also have an influence on lake water temperature and discharge temperature. During 2004, the coldest simulation year, the model predicted cooler discharge temperatures than in 2005 through 2007, the other low-pool years. No discernable impact was observed in predicted discharge DO concentrations as a result of pool elevation.

Coldwater habitat (CWH) volume, defined as the volume of water in the reservoir that meets the minimum DO concentration of 5 mg/L and a maximum temperature of 15 to 19.4^{o}C, reflected the same trends as a function of pool elevation (volume of storage). A greater volume of CWH was predicted with a higher pool elevation (volume of storage) as in 2008 and cooler ambient air temperatures as observed in 2004.

Simulations of a hypothetical high-level reservoir withdrawal at intake elevation 658.4 meters (2160 feet-msl) revealed that the high-level intake could increase discharge temperatures by 4.0^{o}C during summer thermal stratification and increase discharge dissolved oxygen concentrations by 1.0 to 2.0 mg/L during summer thermal stratification. Coldwater habitat volume savings as a result of the high-level withdrawal ranged from 0.22 to 1.21 million acre feet (MAF) when coldwater habitat was at its annual minimum level.

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1 INTRODUCTION

1.1 APPLICATION OF THE CE-QUAL-W2 HYDRODYNAMIC AND WATER QUALITY MODEL TO THE MISSOURI RIVER MAINSTEM SYSTEM RESERVOIRS

1.1.1 WATER QUALITY MODELING NEED

A priority water quality management need identified by the Omaha District (District) is the capability to quantifiably assess, with acceptable uncertainty, the affects that operation and regulation of the six Missouri River Mainstem System (Mainstem System) projects have on water quality of the Missouri River and the impounded reservoirs (USACE, 2009). To meet this need, the District developed a plan to apply the CE-QUAL-W2 Hydrodynamic and Water Quality Model to the six Mainstem System reservoirs: Fort Peck (Montana), Garrison (North Dakota), Oahe (North and South Dakota), Big Bend (South Dakota), Fort Randall (South Dakota), and Gavins Point (South Dakota and Nebraska). The District is approaching application of the CE-QUAL-W2 model to the Mainstem System reservoirs as an ongoing, iterative process. Water quality data is collected at the reservoirs and the model is applied and calibrated. The goal is to have linked, fully-functioning water quality models in place for all the Mainstem System reservoirs that meets the uncertainty requirements of appropriate decision-makers.

CE-QUAL-W2 is a "state-of-the-art" model that can greatly facilitate addressing water quality management issues at the Mainstem System projects. CE-QUAL-W2 mechanistically models basic physical, chemical, and biological processes such as temperature, nutrient, algae, dissolved oxygen, organic matter, and sediment relationships. Once applied and calibrated, the model can reliably predict reservoir water quality conditions based on changes in environmental conditions or project operations and regulation. The ability to reliably predict reservoir water quality conditions under different environmental, operational, and regulation situations will allow the District to determine if water quality at specific projects may be impacted by project operations and regulation. As such, the model will allow the District to proactively assess how proposed project operations and regulation may affect water quality, and allow appropriate water quality management measures to be identified and implemented.

1.1.2 PRIOR APPLICATION OF THE CE-QUAL-W2 MODEL TO THE MAINSTEM SYSTEM RESERVOIRS

An early version of the CE-QUAL-W2 model was applied to four of the Mainstem System reservoirs in the early 1990's (i.e., Ft. Peck, Garrison, Oahe, and Fort Randall). The application of the model was part of the supporting technical documentation of the Environmental Impact Statement (EIS) that was prepared for the Missouri River Master Water Control Manual Review and Update Study. The results of the model application were included as an Appendix to the Review and Update Study – "Volume 7B: Environmental Studies, Reservoir Fisheries, Appendix C – Coldwater Habitat Model, Temperature and Dissolved Oxygen Simulations for the Upper Missouri River Reservoirs" (Cole et. al., 1994). The report (Cole et. al, 1994) provided results of applying the model to the four reservoirs regarding the effects of operational changes on coldwater fish habitat in the reservoir. This early application of the model represents the best results that could be obtained based on the model version and water quality data available at that time, and provided predictive capability for two system operational variables of concern; end-of-month stages and monthly average releases.

Although application of the early CE-QUAL-W2 model met its intended purpose at the time, a lack of available water quality data placed limitations on its full utilization. These limitations were discussed in the Master Water Control Review and Update Study report (Cole et. al, 1994). The following excerpt is taken from that report:

"Steps should be taken to obtain a suitable database that can be used to calibrate the entire suite of water quality algorithms in the model. It is almost a certainty that water quality issues will remain important in the future."

The current version of the CE-QUAL-W2 model has incorporated numerous enhancements over the earlier version that was applied to the four Mainstem System reservoirs in the early 1990's. These enhancements, among other things, include improvements to the numerical solution scheme, water quality algorithms, two-dimensional modeling of the water basin, code efficiencies, and user-model interface. Communication with the author of the earlier version of the CE-QUAL-W2 model applied to the Mainstem System reservoirs and current model support personnel indicated that the District should pursue implementing the current version of the model (personal communication, Thomas M. Cole, USACE/ERDC).

1.1.3 CURRENT APPLICATION OF THE CE-QUAL-W2 MODEL TO THE MAINSTEM SYSTEM RESERVOIRS

The plan for applying the current CE-QUAL-W2 model to a single Mainstem System reservoir encompasses a 5-year period. During years 1 through 3 an intensive water quality survey is conducted on the reservoir to collect the water quality data needed to fully apply the model. Application and calibration of the model occurs in years 4 and 5. Resource limitations required that the initiation of intensive water quality surveys at the Mainstem System reservoirs be staggered annually. The order and year of initiation of the intensive water quality surveys at the Mainstem System reservoirs are: 1) Garrison (2003), 2) Fort Peck (2004), 3) Oahe (2005), 4) Fort Randall (2006), 5) Big Bend (2008), and Gavins Point (2008). Once calibrated for a project, the model will be used to develop a water quality management report and objectives for each of the Mainstem System projects.

This report documents the application of the CE-QUAL-W2 model to Fort Peck Reservoir in Montana.

1.2 REGULATION OF THE MAINSTEM SYSTEM

The Mainstem System is a hydraulically and electrically integrated system that is regulated to obtain the optimum fulfillment of the multipurpose benefits for which the dams and reservoirs were authorized and constructed. The Congressionally authorized purposes of the Mainstem System are flood control, navigation, hydropower, water supply, water quality, irrigation, recreation, and fish and wildlife (including threatened and endangered species). The Mainstem System is operated under the guidelines described in the Missouri River Mainstem System Master Water Control Manual, (Master Manual) (USACE-RCC, 2004). The Master Manual details reservoir regulation for all authorized purposes as well as emergency regulation procedures in accordance with the authorized purposes.

Mainstem System regulation is, in many ways, a repetitive annual cycle that begins in late winter with the onset of snowmelt. The annual melting of mountain and plains snow packs along with spring and summer rainfall produces the annual runoff into the Mainstem System. In a typical year, mountain snow pack, plains snow pack, and rainfall events respectively contribute 50, 25, and 25 percent of the annual runoff to the Mainstem System. After reaching a peak, usually during July, the amount of water stored in the Mainstem System declines until late in the winter when the cycle begins anew. A similar pattern may be found in rates of releases from the Mainstem System, with the higher levels of flow from mid-March to late November, followed by low rates of winter discharge from late November until mid-March, after which the cycle repeats.

To maximize the service to all the authorized purposes, given the physical and authorization limitations of the Mainstem System, the total storage available in the Mainstem System is divided into four regulation zones that are applied to the individual reservoirs. These four regulation zones are: 1) Exclusive Flood Control Zone, 2) Annual Flood Control and Multiple Use Zone, 3) Carryover Multiple Use Zone, and 4) Permanent Pool Zone.

1.2.1 EXCLUSIVE FLOOD CONTROL ZONE

Flood control is the only authorized purpose that requires empty space in the reservoirs to achieve the objective. A top zone in each Mainstem System reservoir is reserved for use to meet the flood control requirements. This storage space is used only for detention of extreme or unpredictable flood flows and is evacuated as rapidly as downstream conditions permit, while still serving the overall flood control objective of protecting life and property. The Exclusive Flood Control Zone encompasses 4.7 MAF and represents the upper 6 percent of the total Mainstem System storage volume. This zone, from 73.3 MAF down to 68.7 MAF, is normally empty. The four largest reservoirs, Fort Peck, Garrison, Oahe, and Fort Randall, contain 97 percent of the total storage reserved for the Exclusive Flood Control Zone.

1.2.2 ANNUAL FLOOD CONTROL AND MULTIPLE USE ZONE

An upper “normal operating zone” is reserved annually for the capture and retention of runoff (normal and flood) and for annual multiple-purpose regulation of this impounded water. The Mainstem System storage capacity in this zone is 11.7 MAF and represents 16 percent of the total Mainstem System storage. This storage zone, which extends from 68.7 MAF down to 57.0 MAF, will normally be evacuated to the base of this zone by March 1 to provide adequate storage capacity for capturing runoff during the next flood season. On an annual basis, water will be impounded in this zone, as required to achieve the Mainstem System flood control purpose, and also be stored in the interest of general water conservation to serve all the other authorized purposes. The evacuation of water from the Annual Flood Control and Multiple Use Zone is scheduled to maximize service to the authorized purposes that depend on water from the Mainstem System. Scheduling releases from this zone is limited by the flood control objective in that the evacuation must be completed by the beginning of the next flood season. This is normally accomplished as long as the evacuation is possible without contributing to serious downstream flooding. Evacuation is, therefore, accomplished mainly during the summer and fall because Missouri River ice formation and the potential for flooding from higher release rates limit release rates during the December through March period.

1.2.3 CARRYOVER MULTIPLE USE ZONE

The Carryover Multiple Use Zone is the largest storage zone extending from 57.0 MAF down to 18.0 MAF and represents 53 percent of the total Mainstem System storage volume. Serving the authorized purposes during an extended drought is an important regulation objective of the Mainstem System. The Carryover Multiple Use Zone provides a storage reserve to support authorized purposes during drought conditions. Providing this storage is the primary reason the upper three reservoirs of the Mainstem System are so large compared to other Federal water resource projects. The Carryover Multiple Use Zone is often referred to as the “bank account” for water in the Mainstem System because of its role in supporting authorized purposes during critical dry periods when the storage in the Annual Flood Control and Multiple Use Zone is exhausted. Only the reservoirs at Fort Peck, Garrison, Oahe, and Fort Randall have this storage as a designated storage zone. The three larger reservoirs (Fort Peck, Garrison, and Oahe) provide water to the Mainstem System during drought periods to provide for authorized purposes. During drought periods, the three smaller projects (i.e., Fort Randall, Big Bend, and Gavins Point) reservoir levels are maintained at the same elevation they would be at if runoff conditions were normal.

1.2.4 PERMANENT POOL ZONE

The Permanent Pool Zone is the bottom zone that is intended to be permanently filled with water. The zone provides for future sediment storage capacity and maintenance of minimum pool levels for power heads, irrigation diversions, water supply, recreation, water quality, and fish and wildlife. A drawdown into this zone is generally not scheduled except in unusual conditions. The Mainstem System storage capacity in this storage zone is 18.0 MAF and represents 25 percent of the total storage volume. The Permanent Pool Zone extends from 18.0 MAF down to 0 MAF.

1.2.5 WATER CONTROL PLAN FOR THE MAINSTEM SYSTEM

Variations in runoff into the Mainstem System necessitates varied regulation plans to accommodate the multipurpose regulation objectives. The two primary high-risk flood seasons are the plains snowmelt and rainfall season extending from late February through April, and the mountain snowmelt and rainfall period extending from May through July. Also, the winter ice-jam flood period extends from mid-December through February. The highest average power generation period extends from mid-April to mid-October, with high peaking loads during the winter heating season (mid-December to mid-February) and the summer air conditioning season (mid-June to mid-August). The power needs during the winter are supplied primarily with Fort Peck and Garrison Dam releases and the peaking capacity of Oahe and Big Bend Dams. During the spring and summer period, releases are normally geared to navigation and flood control requirements, and primary power loads are supplied using the four lower dams. The normal 8-month navigation season extends from April 1 through November 30, during which time Mainstem System releases are increased to meet downstream target flows in combination with downstream tributary inflows. Winter releases after the close of the navigation season are much lower and vary depending on the need to conserve or evacuate storage volumes, downstream ice conditions permitting. Releases and pool fluctuations for fish spawning management generally occur from April 1 through June. Two threatened and endangered bird species, piping plover (*Charadrius melodus*) and least tern (*Sterna antillarum*), nest on “sandbar” areas from early May through mid-August. Other factors may vary widely from year to year, such as the amount of water-in-storage and the magnitude and distribution of inflow received during the coming year. All these factors will affect the timing and magnitude of Mainstem System releases. The gain or loss in the water stored at each reservoir must also be considered in scheduling the amount of water transferred between reservoirs to achieve the desired storage levels and to generate power. These items are continually reviewed as they occur and are appraised with respect to the expected range of regulation.

1.3 DESCRIPTION OF THE FORT PECK PROJECT

Fort Peck Dam and Reservoir are authorized for the purposes of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. Habitat for one endangered species, pallid sturgeon (*Scaphirhynchus albus*), occurs in the Missouri River upstream and downstream of the reservoir.

1.3.1 FORT PECK DAM AND POWERPLANT

Fort Peck Dam is located on the Missouri River at river mile (RM) 1771.5 in northeastern Montana, 17 miles southeast of Glasgow, Montana. Construction of the Fort Peck project was initiated in 1933, and embankment closure was made in 1937. The Fort Peck Dam embankment is nearly 4 miles long (excluding the spillway) and rises over 250 feet above the original streambed. Fort Peck Dam remains the largest dam embankment in the United States (126 million cubic yards of fill), the second largest volume embankment in the world, and the largest “hydraulic fill” dam in the world. The concrete spillway is over 1 mile long and is located in a natural saddle of the reservoir rim about 3 miles east of the dam. In 1943, the first hydropower unit of the three units in the first powerplant went on line, and the third unit became operational in 1951. Construction of a second powerplant began in the late 1950's and the two units of this plant became operational in 1961. The five generating units at Fort Peck Dam produce an annual average 1.06 million mega-watt hours of electricity valued in excess of $17 million in revenue.

The Fort Peck Dam outlet works consists of a submerged intake structure and four concrete diversion tunnels, varying in length from 5,700 to 7,200 feet, which extend through the east abutment of the dam. The submerged intake structure, at the upstream end of the tunnels, is approximately 517 feet in length, 57 feet in width (at top), and 65 feet in height (i.e., crest elevation 2095 ft-msl). It is divided into four individual water intake chambers by three 15-foot thick concrete cross walls and equipped with removable steel trash racks. The intake floor of the tunnel portals is at elevation 2030 ft-msl. Tunnels 1 and 2 have steel liners downstream of the control shafts to supply flows to powerplants 1 and 2 respectively. Tunnels 3 and 4 were designed for emergency flood releases and have not been used in recent years.

1.3.2 FORT PECK RESERVOIR

The closing of Fort Peck Dam in 1937 resulted in the formation of Fort Peck Reservoir. The Permanent Pool Zone (inactive storage) of the reservoir was initially filled (elevation 2150) in April 1942 and the Carryover Multiple Use Zone (elevation 2234) first filled 5 years later in 1947. Drought conditions during the late 1950's, combined with withdrawals to provide water for the initial fill of the other Mainstem System projects, resulted in a drawdown of the reservoir level to elevation 2167.4 ft-msl in early 1956, followed by a generally slow increase in pool elevation. The Carryover Multiple Use Zone was finally refilled in June 1964. Generally, the reservoir has remained filled from that time with the exception of the droughts of 1987 to 1993 and 2000 to date. Exclusive flood control storage space was first used in 1969 and then again in 1970, 1975, 1976, 1979, 1996, and 1997. In 1975, a maximum reservoir level of 2251.6 ft-msl, 1.6 feet above the top of the Exclusive Flood Control Zone, occurred. Due to drought conditions, the reservoir, at the end of December 2006, was 34.5 feet below the pool elevation of 2234 ft-msl, which is the top of the Carryover Multiple Use Zone. Although still experiencing lower pool levels due to previous drought conditions, the reservoir did recover to a pool elevation of 2210.0 ft-msl at the end of December 2008.

When full, Fort Peck Reservoir is 134 miles long, covers 246,000 acres, and has 1,520 miles of shoreline. Table 1.1 summarizes how the surface area, volume, mean depth, and retention time of Fort Peck Reservoir vary with pool elevations. Major inflows to Fort Peck Reservoir are the Missouri River, Musselshell River, and Big Dry Creek. The reservoir is used as a water supply by the town of Fort Peck, Montana and by numerous individual cabins in the area. The water supply for the town of Fort Peck is obtained from a 10-inch raw water line that taps into the penstock to Unit 3. Cooling water for the individual units in the Fort Peck powerplant is drawn from the water going through the units. Fort Peck Reservoir is an important recreational resource and a major visitor destination in Montana.

Table 1.1. Surface area, volume, mean depth, and retention time of Fort Peck Reservoir at different pool elevations.

Pool Elevation (Feet-msl)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
2250	245,405	18,462,840	75.2	2.55
2245	237,605	17,253,500	72.6	2.38
2240	225,065	16,094,980	71.5	2.22
2235	213,025	15,000,180	70.4	2.07
2230	201,130	13,964,500	69.4	1.93
2225	188,765	12,991,390	68.8	1.79
2220	180,590	12,069,610	66.8	1.67
2215	171,930	11,188,080	65.1	1.54
2210	163,400	10,349,820	63.3	1.43
2205	154,773	9,554,578	61.7	1.32
2200	146,595	8,801,156	60.0	1.21
2195	138,081	8,090,417	58.6	1.12
2190	132,175	7,415,889	56.1	1.02
2185	126,146	6,769,319	53.7	0.93
2180	118,608	6,156,918	51.9	0.85
2175	111,285	5,582,093	50.2	0.77
2170	103,394	5,045,002	48.8	0.70
2165	95,316	4,549,151	47.7	0.63
2160	89,461	4,087,903	45.7	0.56

Average Annual Inflow (1967 through 2008) = 7.246 Million Acre-Feet
Average Annual Outflow: (1967 through 2008) = 6.709 Million Acre-Feet
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 2250-2246 ft-msl), Annual Flood Control and Multiple Use Zone (elev. 2246-2234 ft-msl), Carryover Multiple Use Zone (elev. 2234-2160 ft-msl), and Permanent Pool Zone (elev. 2160-2030 ft-msl). All elevations are in the NGVD 29 datum.

1.3.3 MISSOURI RIVER DOWNSTREAM OF FORT PECK DAM

The Missouri River from Fort Peck Dam flows in an easterly direction for about 204 miles in an unchannelized river before entering the headwaters of Garrison Reservoir near Williston, North Dakota. Major tributaries include the Milk, Poplar, and Yellowstone Rivers. The Yellowstone River enters the Missouri River just upstream of the Garrison Reservoir delta and influences only a short segment of the Fort Peck reach. The reach of the Missouri River from Fort Peck Dam to Garrison Reservoir has been identified as a priority area for the recovery of the endangered pallid sturgeon. Water supply intakes for several municipalities are located on this reach. The water supply intakes for the Fort Peck National Fish Hatchery and the town of Glasgow, MT are located in the Fort Peck Dam tailwaters area. The water supply intake manifold for the Fort Peck National Fish Hatchery is located in the dredge cuts just downstream of the dam, and the water supply intake for the town of Glasgow is located in the Nelson dredge approximately 3 miles downstream of the dam.

Releases of water from Fort Peck Dam into the Missouri River average about 10,000 cfs, with slightly more in wet years and slightly less in drought years. Channel capacity below Fort Peck Dam is approximately 35,000 cfs. Daily winter releases are generally 10,000 to 13,000 cfs during “normal” water years. Full hydropower capacity is 15,000 cfs. During 1975, a significant flood year, releases averaged 35,000 cfs in July. Minimum hourly releases, particularly during fish spawning, have been requested from Fort Peck. Although a year-round instantaneous minimum release of 3,000 cfs has been established to protect the trout fishery located in the dredge cuts immediately downstream of Fort Peck Dam, an attempt is made to keep releases above 4,000 cfs.

1.4 WATER QUALITY MANAGEMENT CONCERNS AT THE FORT PECK PROJECT

1.4.1 APPLICABLE WATER QUALITY STANDARDS

1.4.1.1 Fort Peck Reservoir

The State of Montana has assigned Fort Peck Reservoir a B-3 classification in the State's water quality standards. As such, the reservoir is to be maintained suitable for drinking, culinary, and food processing purposes, after conventional treatment; bathing, swimming, and recreation; growth and propagation of non-salmonid fishes and associated aquatic life, waterfowl, and furbearers; and agricultural and industrial water supply. Although not assigned, a coldwater fishery currently exists in Fort Peck Reservoir, and coldwater aquatic life would seemingly be protected under the anti-degradation provisions of the State of Montana's water quality standards and the Federal Clean Water Act (CWA).

1.4.1.2 Missouri River Downstream of Fort Peck Dam

The Missouri River downstream of Fort Peck Dam has been assigned, in the State of Montana's water quality standards, a B-2 classification from the dam to the confluence of the Milk River and a B-3 classification from the Milk River confluence to the Montana/North Dakota state line. Both B-2 and B-3 waters are to be maintained suitable for drinking, culinary and food processing purposes, after conventional treatment; bathing, swimming and recreation; waterfowl and furbearers; and agricultural and industrial water supply. In addition, B-2 waters are to maintain growth and marginal propagation of salmonid fishes and associated aquatic life, and B-3 waters are to maintain growth and propagation of non-salmonid fishes and associated aquatic life.

1.4.2 FEDERAL CLEAN WATER ACT SECTION 303(D) IMPAIRED WATER BODY LISTINGS

1.4.2.1 Fort Peck Reservoir

Pursuant to Section 303(d) of the Federal CWA, Montana has placed Fort Peck Reservoir on the state's list of impaired waters citing impairment to the uses of drinking water supply and primary contact recreation due to the pollutants of lead, mercury, metals, and noxious aquatic plants. The identified sources of these pollutants are agriculture, resource extraction, abandoned mining, atmospheric deposition, debris, and bottom deposits. The State of Montana has also issued a fish consumption advisory for Fort Peck Reservoir due to mercury concerns.

1.4.2.2 Missouri River Downstream of Fort Peck Dam

The Missouri River downstream of Fort Peck Dam has been placed on the State of Montana's list of impaired waters citing impairment to the uses of aquatic life support, coldwater fishery – trout, and warmwater fishery due to the stressors of flow alteration, riparian degradation, thermal modifications, and other habitat alterations. The identified probable sources of these stressors are flow regulation/modification and hydromodification. No fish consumption advisory has been issued for the Missouri River downstream of Fort Peck Dam by the State of Montana.

1.4.3 MAINTENANCE OF A "TWO-STORY" RECREATIONAL FISHERY IN FORT PECK RESERVOIR

Recreation at Fort Peck Reservoir is of great economic importance to the State of Montana, especially with respect to the reservoir's fishery. Fort Peck Reservoir currently maintains a "two-story" fishery in that the reservoir fishery is comprised of warmwater and coldwater species. The ability of the reservoir to maintain a "two-story" fishery is due to the reservoir's thermal stratification in the summer into a colder bottom region and warmer surface region. Warmwater species present in the reservoir that are recreationally important include walleye (*Sander vitreus*), sauger (*Sander canadensis*), northern pike

(*Esox lucius*), smallmouth bass (*Micropterus dolomieu*), catfish (*Ictalurus spp.*), and yellow perch (*Perca flavescens*). Coldwater species present in the reservoir that are recreationally important include chinook salmon (*Oncorhynchus tshawytscha*) and lake trout (*Salvelinus namaycush*). Chinook salmon are maintained in the reservoir through regular stocking. A primary forage fish utilized by all sport fishes in the reservoir is the lake cisco (*Coregonus artedii*) – a coldwater species. Since it is a primary forage fish in Fort Peck Reservoir, fluctuations in the cisco population can have a ripple effect throughout the reservoir's entire recreational sport fishery. The recent pool-level drawdowns of Fort Peck Reservoir, due to the ongoing drought conditions in the interior western United States have reduced the amount of coldwater habitat available in Fort Peck Reservoir.

Two water quality parameters, temperature and dissolved oxygen, are of prime importance regarding the maintenance of coldwater fishery habitat in Fort Peck Reservoir. As the pool level of Fort Peck Reservoir falls, the amount of coldwater habitat available at lower reservoir depths during summer thermal stratification is reduced. During summer thermal stratification, the reservoir also experiences degradation of dissolved oxygen at lower reservoir depths as accumulated organic matter is decomposed. The situation could be of most concern later in the summer when the reduced volume of colder water combined with the degradation of dissolved oxygen in the deeper water of the reservoir act together to possibly limit the coldwater habitat volume.

1.4.4 WATER QUALITY FOR THE ENHANCEMENT OF PALLID STURGEON POPULATIONS IN THE MISSOURI RIVER DOWNSTREAM OF FORT PECK DAM

One of the few remaining populations of pallid sturgeon occurs in the Missouri River between Fort Peck Dam and the headwaters of Garrison Reservoir. Individuals in this population also inhabit the lower Yellowstone River. As such, this reach of the Missouri River has been identified as a priority recovery area for the pallid sturgeon (USFWS, 1993). It is hypothesized that the building and operation of Fort Peck Dam and Reservoir have adversely impacted the pallid sturgeon in this reach of the Missouri River by regulating flows, lowering water temperatures, reducing sediment and nutrient transport, and increasing water clarity.

Historically, the lower Missouri River in Montana was a turbid, warmwater environment with seasonally fluctuating flows. The sediment and turbidity of the water through these cycles contributed significantly to the evolution of the pallid sturgeon. The fish adapted to highly turbid and low visibility environments by physiologically evolving to enhance their ability to capture prey and avoid capture as juveniles and larvae in this low visibility environment. It is also believed that the pallid sturgeon adapted by developing spawning cues based on historical conditions in the river. The fish requires a spawning cue of suitable magnitude, duration, and timing to complete this life cycle element. It is believed that increasing flow and water temperature in the late spring is a primary factor for pallid sturgeon to initiate spawning.

Water temperature is believed to be a controlling factor on the pallid sturgeon in this reach of the Missouri River in regards to spawning cues and larval survival during the summer. Because Fort Peck Dam has a deepwater withdrawal from the reservoir, water temperature in the Missouri River downstream of the dam are appreciably colder than "pre-dam" conditions. A water temperature of around 18°C (64.4°F) is believed necessary to initiate a spawning response in pallid sturgeon. Additionally, a dramatic decline in water temperatures after spawning can affect larval pallid sturgeon development and likely adversely affect the production and availability of suitable forage (i.e., plankton and other invertebrate species) for the juvenile pallid sturgeon throughout the summer. Low water temperatures may induce mortality in young pallid sturgeon. With this in mind, a late-spring/early-summer water temperature of 18°C in the Missouri River at Frazer Rapids (approximately 25 miles downstream of Fort peck Dam) has been identified as critical for pallid sturgeon spawning and recruitment in this reach of the river.

Fort Peck Reservoir is trapping sediment that historically moved down the Missouri River through the reach downstream of the dam. It is also believed that the current colder water temperatures in the river are likely suppressing production of plankton and other invertebrate organisms that contribute to turbidity of the water. The resulting clearer water is believed to adversely affect young pallid sturgeon by making them more vulnerable to sight-feeding predators and increasing competition for food by sight-adapted predators. In addition, adult fish may be adversely affected by the increased ability of prey to avoid capture in clearer water.

2 MODEL METHODS

2.1 CE-QUAL-W2

CE-QUAL-W2 is a two-dimensional (longitudinal and vertical) water quality and hydrodynamic model for rivers, estuaries, lakes, reservoirs, and river basin systems. CE-QUAL-W2 simulates basic physical, chemical, and biological processes such as temperature, nutrient, algae, dissolved oxygen, organic matter, and sediment relationships. The model is supported by the Environmental Lab at the USACE Engineering Research and Development Center (ERDC) Waterways Experiment Station (WES) in Vicksburg, MS, and by the Civil Engineering Department at Portland State University in Portland, OR.

Version 2.0 of the CE-QUAL-W2 model was applied to four of the upper Mainstem System Projects in the early 1990s (i.e., Ft. Peck Lake, Lake Sakakawea, Lake Oahe, and Lake Francis Case). The application of the model was part of the supporting technical documentation of the Environmental Impact Statement (EIS) that was prepared for the Missouri River Master Water Control Manual Review and Update Study. The results of the model application were included as an Appendix to the Review and Update Study – "Volume 7B: Environmental Studies, Reservoir Fisheries, Appendix C – Coldwater Habitat Model, Temperature and Dissolved Oxygen Simulations for the Upper Missouri River Reservoirs" (Cole et. al., 1994).

The Version 3.2 was used to model temperature, dissolved oxygen, and nutrients in Fort Peck Lake. Predicted temperatures in the lake will be influenced by reservoir inflow volumes and temperatures; environmental factors such as wind, air temperature, and solar radiation; and management factors such as reservoir release rates and outflow structure configurations.

All model calculations and outputs are performed in the International System (SI) of Units; therefore, all subsequent data and figures presented in this report are expressed in SI units with the exception of coldwater habitat which is expressed in traditional English units of acre feet.

2.2 HYDRODYNAMICS

The governing equations for hydrodynamics and transport are derived from the conservation of fluid mass and momentum equation. The model uses a hydrostatic approximation for vertical fluid movement rather than rely on the true conservation of momentum equation. Hydrodynamics and transport are laterally and layer averaged meaning lateral and layer variations in velocities, temperatures and constituents are negligible. The hydrodynamic behavior of the model is dependent largely on initial conditions, boundary conditions, and hydraulic conditions which are described with specific regard to the Fort Peck Lake model in the following paragraphs and later sections of this report.

2.2.1 INITIAL CONDITIONS

Annual simulations were performed from January 1 (jday = 1) to December 31 (jday = 365) with a minimum timestep of 1 minute. The initial water column temperature was set to 1.0°C, which is approximately the average simulated water temperature at the end of the simulation year. An initial ice thickness of 0.28 meters (0.9 ft) covering the entire reservoir on January 1 was assumed in all simulation years.

2.2.2 HYDRAULIC COEFFICIENTS

CE-QUAL-W2 uses default values for a number of hydraulic parameters that influence the movement of momentum and heat exchange within a water body (Table 2-1). The horizontal dispersion of momentum and heat are determined by the horizontal eddy viscosity and diffusivity, while vertical diffusion of momentum is influenced by the method for computing the vertical eddy viscosity. A very important factor influencing momentum transfer and mixing near the bottom of a water body is the bottom friction expressed either as Manning's roughness or Chezy coefficients. In the Fort Peck Lake model, Chezy coefficients ranging from 70 to 100 were used throughout the entire water body.

Table 2-1. CE-QUAL-W2 hydraulic and heat exchange coefficients.

Hydraulic Coefficients	
Horizontal Eddy Viscosity & Diffusivity (m^2/s)	10.0
Vertical Eddy Viscosity Method	TKE
Max. Vertical Eddy Viscosity (m^2/s)	0.001
Friction Type (Chezy)	70 - 100
Heat Exchange Coefficients	
Sediment Heat Exchange Coefficient (W/ m^2/s)	0.3
Bottom Sediment Temperature (^oC)	10
Fraction Solar Radiation at Sediment to Water	0.25
Coefficient of water-ice heat exchange	10
Ice Albedo (Reflection/Incident)	0.25
Fraction of Radiation Absorbed by Ice	0.5
Solar Radiation Extinction Coefficient (m^{-1})	0.07
Temperature for ice formation (^oC)	2.5
Wind Measurement Height (m)	10.0
Fraction of solar radiation absorbed at WS	0.45

2.2.3 HEAT EXCHANGE

Water surface heat exchange is defined as the sum of incident short and long wave solar radiation, reflected short and long wave solar radiation, back radiation, evaporative heat loss, and heat conduction. Since some of these computed terms are temperature dependent, the Fort Peck Lake model uses an equilibrium temperature method in which the net rate of surface heat exchange is zero at the equilibrium temperature. Although this method is empirical in nature, it consistently gives better results than other theoretical methods. A number of heat exchange coefficients that affect ice formation and transfer of heat through ice are specified in Table 2-1.

Heat is transferred between the bottom sediment-water interface, and a heat exchange rate along with average sediment temperature must be specified. The fraction of solar radiation re-radiating from the lake bottom to the water column is specified as a fraction of radiation reaching the bottom. In Fort Peck Lake very little shortwave solar radiation reaches the lake bottom.

The wind measurement height is particularly important because the model adjusts wind speed to the height of the wind speed formulation which drives surface mixing and evaporative heat losses. In addition the fraction of solar radiation absorbed by the water surface is specified.

2.3 WATER QUALITY

CE-QUAL-W2 computes numerous water quality constituents in their basic forms and derived forms based on a constituent mass balance. Within this mass balance constituents may undergo kinetic reactions that convert the nutrient to other organic or inorganic forms of the nutrient by algae utilization or other biological processes. While nutrients are important in many water quality applications, dissolved oxygen is a more important parameter concerning Fort Peck Lake.

2.3.1 NUTRIENTS

Lake nutrients undergo transport and kinetic reactions through biological or chemical transformation to nutrient sources or sinks. Water quality state variables used in the Fort Peck Lake simulations included total dissolved solids (TDS), suspended solids (SS), bio-available phosphorus, ammonium, nitrate-nitrite, dissolved and particulate silica, total iron, labile and refractory forms of dissolved and particulate organic matter, algae, dissolved oxygen (DO), total inorganic carbon, and alkalinity. Further discussion on how CE-QUAL-W2 handles nutrient kinetics may be found in the Appendix B of the User Manual (Cole and Wells, 2003).

2.3.2 DISSOLVED OXYGEN

A use of the water quality constituent modeling is to compute cold water habitat as a function of dissolved oxygen (and temperature) throughout the reservoir. The most important components that serve as sources of dissolved oxygen in these simulations are aeration from the atmosphere and algae (phytoplankton) photosynthesis, depicted in Figure 2-1. Dissolved oxygen sinks include algal respiration and decay or decomposition of organic sediments and organic matter. Reaeration, organic matter oxygen demand, algal dynamics, and sediment oxygen demand are discussed in more detail.

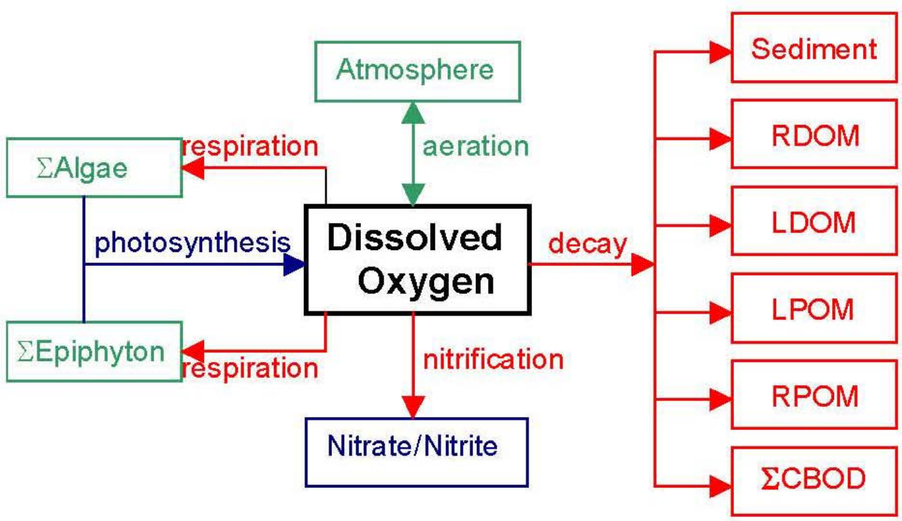

Figure 2-1. Dissolved oxygen dynamics in CE-QUAL-W2.

2.3.2.1 <u>Reaeration</u>

The reaeration of water with dissolved oxygen occurs in lakes as a function of turbulent mixing caused by surface winds. Reaeration by wind primarily effects dissolved oxygen concentrations in the mixed volume of the water column (e.g., epilimnion during summer thermal stratification, etc.). Model equations are written for 10-meter measured wind heights, but can be adjusted for alternate wind heights.

2.3.2.2 <u>Organic Matter</u>

The total oxygen demand exerted on a lake is often measured as biological oxygen demand (BOD); however, both decomposition and production of these materials occurs in the model so organic matter represented as BOD must be separated into its major components, which include labile dissolved organic matter (LDOM), refractory dissolved organic matter (RDOM), labile particulate organic matter

(LPOM), and refractory particulate organic matter (RPOM). Dissolved organic matter (DOM) and particulate organic matter (POM) are important because they utilize dissolved oxygen (DO) during their decay process. Labile DOM and labile POM decays at a faster rate than refractory OM, which is product of labile OM decay. Settling POM contributes to the lake sediment oxygen demand. DOM and POM are produced by algae mortality and excretion. DO concentrations in the reservoir are greatly influenced by organic matter (OM) dynamics. Initial and observed OM concentrations in the lake and inflows were estimated based on measured concentrations of total organic carbon (TOC).

2.3.2.3 Algal Dynamics

Although CE-QUAL-W2 version 3.2 allows algal groups to be broken into several types of algae, one algal group representing both blue-green algae and diatoms was modeled. Algae are important in nutrient and DO dynamics by utilizing nutrients and producing DO during photosynthesis, and utilizing DO during respiration. Algal mortality and excretion produces DOM and POM which eventually decay and further utilize DO. Chlorophyll *a* (Chl *a*) may be used as an indicator of algae present in the reservoir.

2.3.2.4 Sediment Oxygen Demand

Organic sediments resulting from algae and OM decay contribute to nutrients and DO demand. In the reservoir model sediment oxygen demand (SOD) is computed using a constant (zero-order) function and and an organic sediment accumulative (first-order) function. The zero-order function specifies a SOD and nutrient release rates that are temperature dependent. The first-order function, though not a true sediment diagenesis compartment, accumulates organic sediment from settling of algae and POM, therefore it is more predictive in nature than the zero-order function, and it attempts to accurately account for the SOD. Both zero- and first-order SOD methods are used concurrently in the water quality simulations. SOD is important to this model because it influences hypolimnetic DO through DO utilization by decomposition and SOD.

2.3.3 INITIAL CONDITIONS

Initial constituent concentrations were derived from minimum constituent concentrations detected in the ambient water quality samples from the reservoir, with the exception of dissolved oxygen (DO), labile dissolved organic matter (LDOM), and labile particulate organic matter (LPOM). The year end simulated average DO concentration in the reservoir was substituted for the initial DO concentration in the subsequent year. LDOM and LPOM initial concentrations were determined the same way.

3 MODEL SETUP & DATA

3.1 PHYSICAL REPRESENTATION

3.1.1 LAKE BATHYMETRY

The Fort Peck Lake bathymetry was modified from previous CE-QUAL-W2 bathymetry used in the Coldwater Habitat Model constructed by Cole et al. (1994) of the U.S. Army Corps of Engineers Waterways Experiment Station in Vicksburg, MS. The reservoir bathymetry consisted of two main branches, 45 active segments and 32 layers (Figure 3-1). Segments were 5 km (3.1 mi) in length with 2 m (6.56 ft) layer thicknesses. At the multipurpose pool level, segment widths ranged from 11,500 m (37,700 ft) at the dam (Segment 34) to 800 m (2,625 ft) at the lake inlet (Segment 2). Segment orientations were adjusted to match their correct geographic orientation. Chezy's bottom friction coefficients were set to 70. Volume-area-elevation curves constructed from the Corps of Engineers survey and computed from model bathymetry are compared in Figures 3-2 and 3-3, respectively.

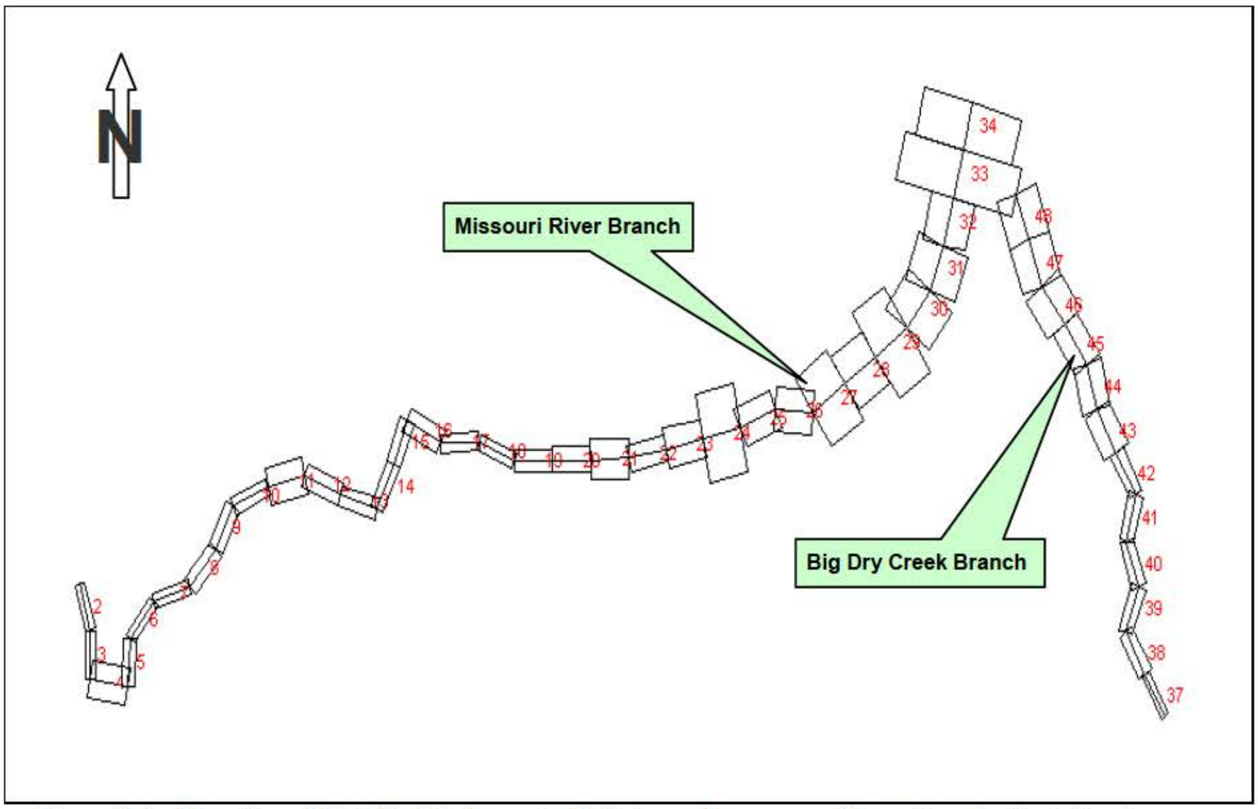

Figure 3-1. Plan view of Fort Peck Lake water body branches, segment layout, and orientation in space.

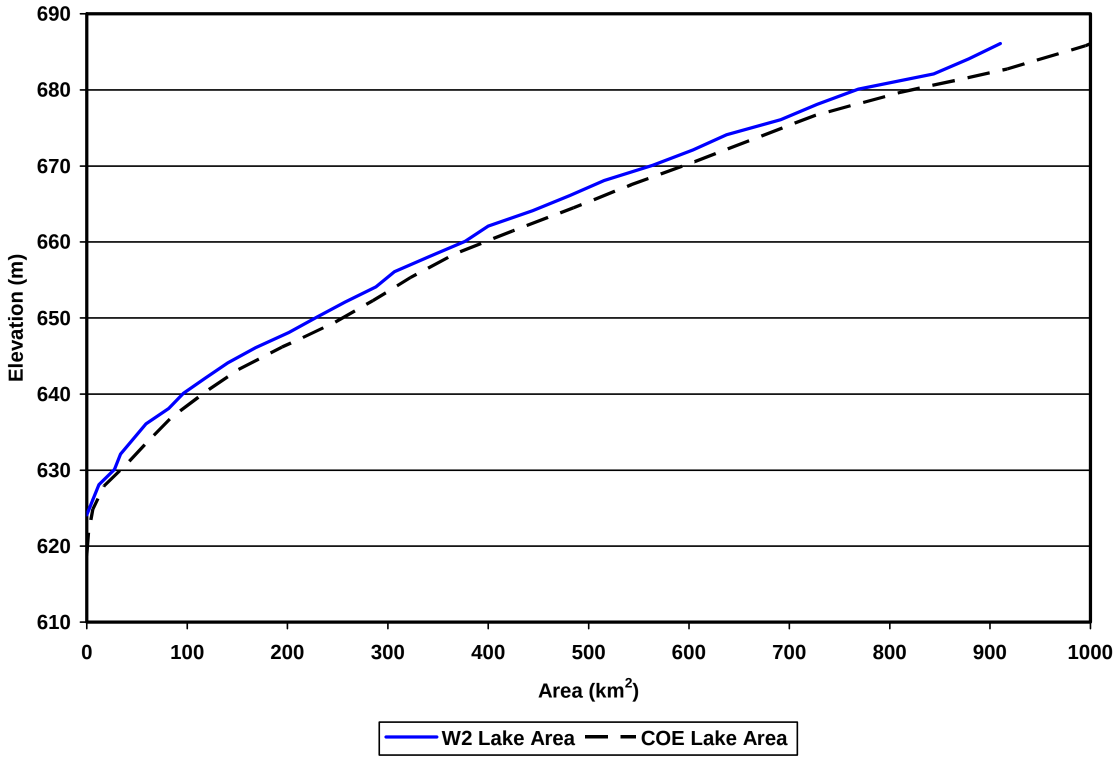

Figure 3-2. Fort Peck Reservoir area-elevation curves computed from the W2 model bathymetry and the 1986 COE lake survey.

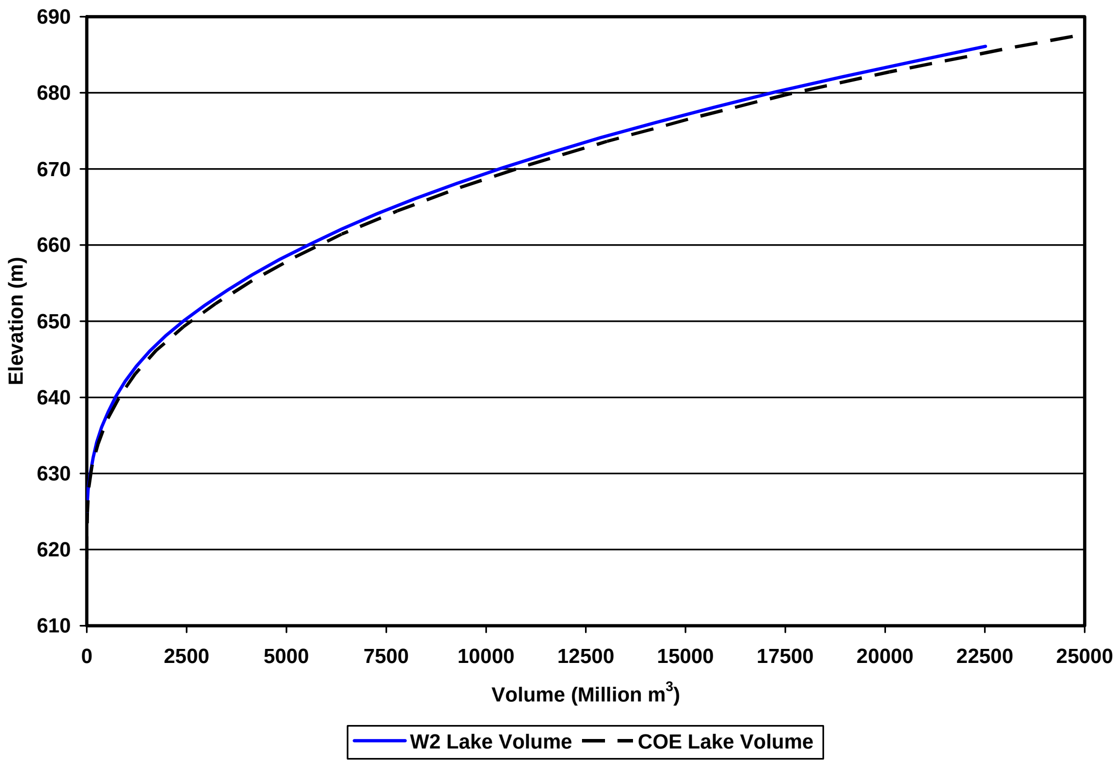

Figure 3-3. Fort Peck Reservoir volume-elevation curves computed from the W2 model bathymetry and the 1986 COE lake survey.

3.1.2 LAKE OUTLET

The Fort Peck Lake outlet works consists of a reservoir inlet portal connected to four tunnels controlled at the dam axis by control shafts. Figure 3-4 is a schematic diagram of the intake portal and intake tunnels. Below the control shafts, two of the tunnels connect to Powerhouses No. 1 and 2, while the third and fourth tunnels outlet directly to the Missouri River. The inlet portal is 157.7 m (517.5 ft) long, 17.4 m (57 ft) wide, and 19.8 m (65 ft) in height. The crest of the inlet portal is at elevation 638.6 m (2,095 ft) and the top of the trash rack is at elevation 644.8 (2,115.5 ft). The minimum multi-purpose pool elevation is 658.4 m (2,160 ft), the maximum normal operation pool is 684.6 m (2,246 ft), and the maximum operating pool is 685.8 m (2,250 ft).

The outlet configuration for the model was set up initially with an intake elevation of 638.6 m (2,095 ft), an inlet bottom limit at Layer 34 or elevation 622.1 m (2,041 ft), and an inlet top limit at Layer 2 or the upper reservoir limit. Calibration of the dam discharge temperatures by adjusting the inlet centerline elevation and lower limit elevation parameters resulted in the intake elevation being set to 641.7 m (2105.3 ft) and the inlet bottom limit set at Layer 31 or elevation 626.1 m (2054.1 ft). Computed outlet temperature results vary in accuracy year by year, yet the overall outlet temperature fit for the specified structure and bottom elevation is good.

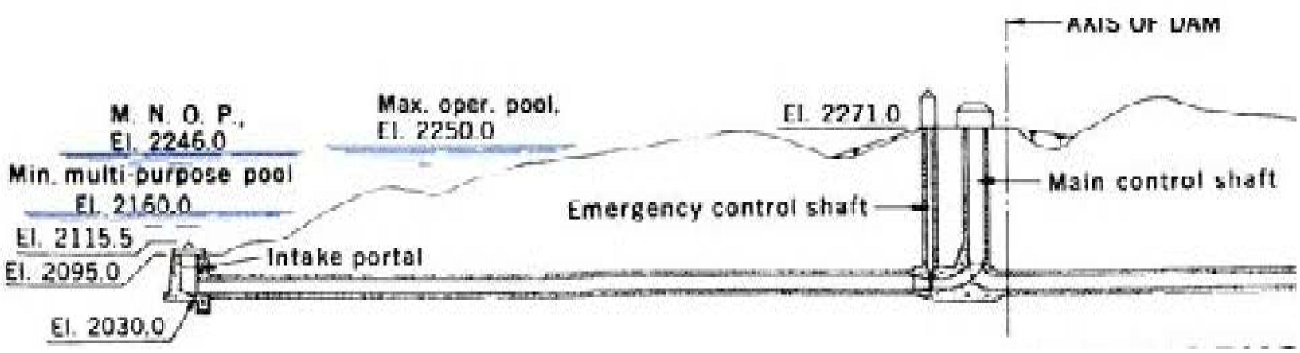

Figure 3-4. Fort Peck Lake outlet works schematic.

3.2 METEOROLOGICAL DATA

CE-QUAL-W2 requires meteorological inputs including air temperature, dew point temperature, wind speed, wind direction, cloud cover and shortwave solar radiation. Cloud cover is used to estimate the amount of shortwave solar radiation reaching the water surface; however, it may be measured directly. Hourly weather data was obtained from the National Climatic Data Center Local Climatological Data online database for all simulations years. The Wokal Field/Glasgow International Airport (GGW) weather station maintained by the airport and the National Weather Service (NWS) provided hourly air temperature, dew point temperature, wind speed, wind direction, and cloud cover. The station coordinates are 48^{o}12'N latitude, 106^{o}37'W longitude, at a ground elevation of 691.3 m (2268 ft).

3.2.1 TEMPERATURE

Hourly ambient air and dew point temperature were measured at GGW and entered into the model. Average daily temperature as well as maximum and minimum hourly air temperature from 2004 to 2007 is plotted in Figure 3-5. Average daily dew point temperature is plotted in Figure 3-6.

3.2.2 WIND DATA

Hourly wind speed and direction are important meteorological inputs, yet wind speed is the most important because it drives mixing in the epilimnion and thus the convection of thermal energy in the water column. Wind speed and direction were measured at a 10 meter height at GGW. Average daily wind speed and maximum hourly wind speed are plotted in Figure 3-7.

3.2.3 WIND SHELTERING COEFFICIENTS

Wind sheltering coefficients are the ratio of transferred wind energy to actual wind energy present in the meteorological data. Wind sheltering coefficients are one of the most important calibration parameters because they directly influence the amount of mixing that occurs in the surface layer of the reservoir and therefore the transfer of heat energy from the water surface to deeper layers in the reservoir. Wind sheltering coefficients ranging from 0.9 to 1.1 were used in the Fort Peck Lake model.

3.2.4 CLOUD COVER

Cloud cover reported qualitatively was converted to a cloud quantity required by the CE-QUAL-W2 program in computing incident solar radiation. Cloud cover is quantified on a scale of 0 to 10, 10 being the greatest amount of cloud cover. The cloud cover quantities that worked best in the Fort Peck Reservoir and Missouri River simulations were two (2) for clear conditions (CLR) and scattered cloud cover (SCT), six (6) for few (FEW) clouds, eight (8) for broken cover (BKN), and ten (10) for overcast (OVC) days.

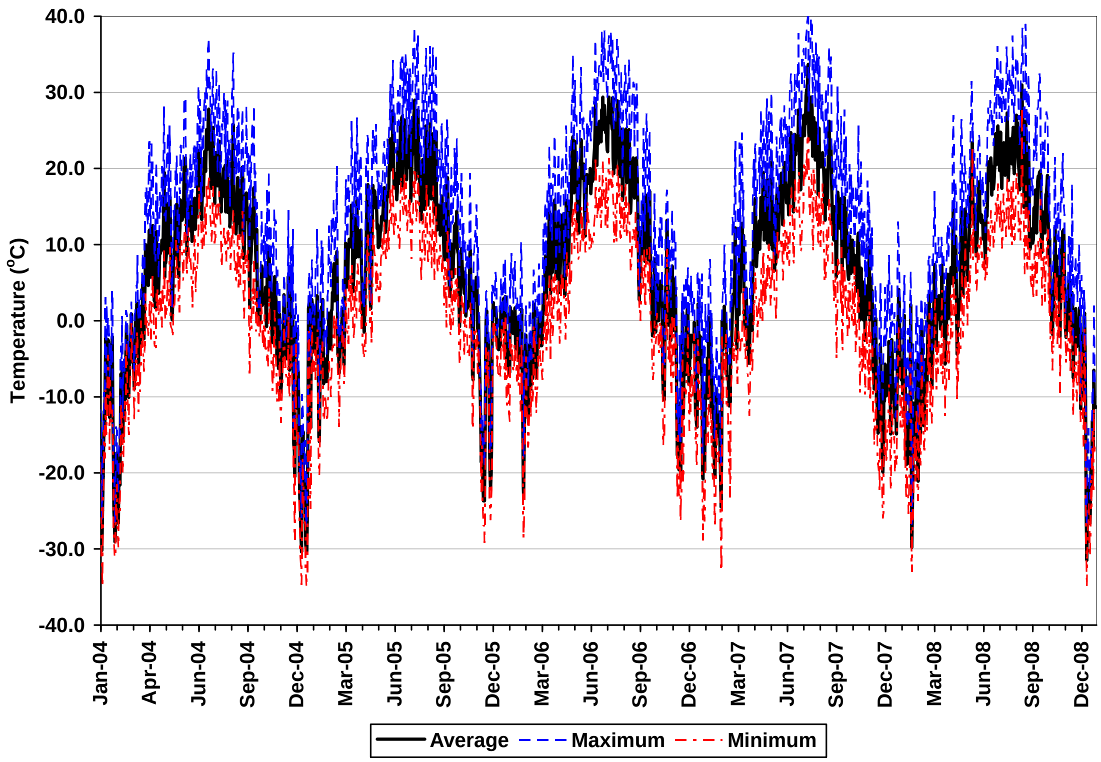

Figure 3-5. Daily average, maximum, and minimum air temperatures at Glasgow International Airport, Glasgow, MT.

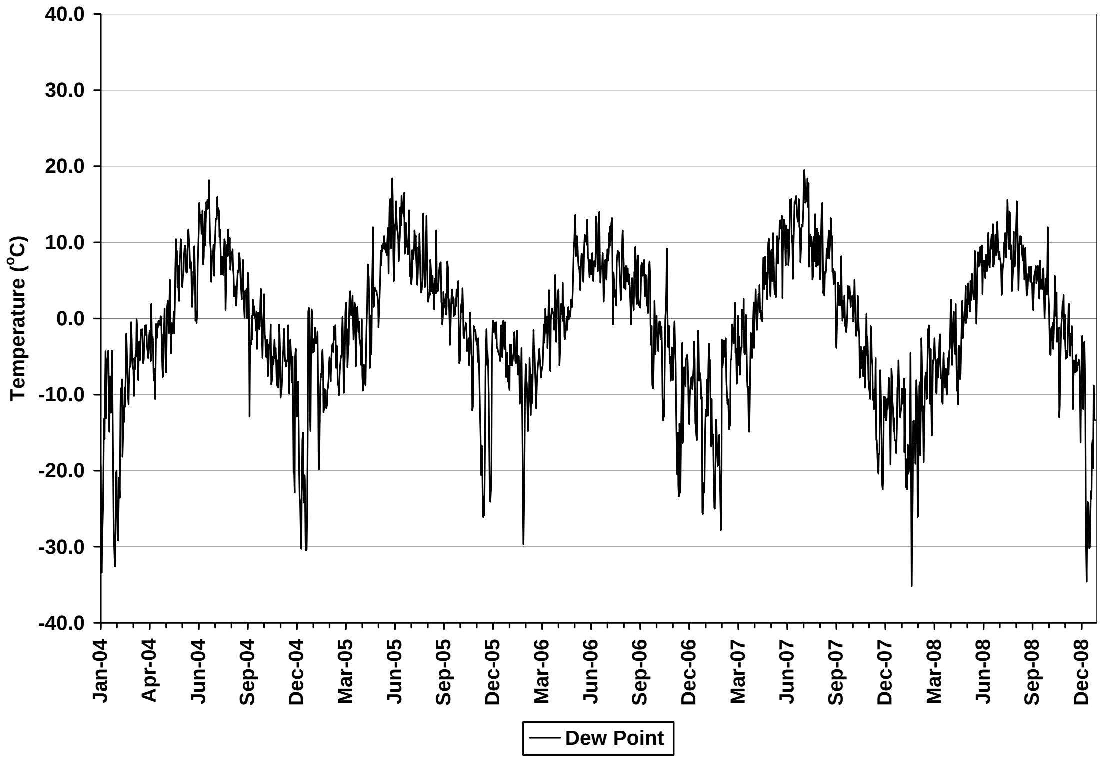

Figure 3-6. Daily average dew point temperature at Glasgow International Airport, Glasgow, MT.

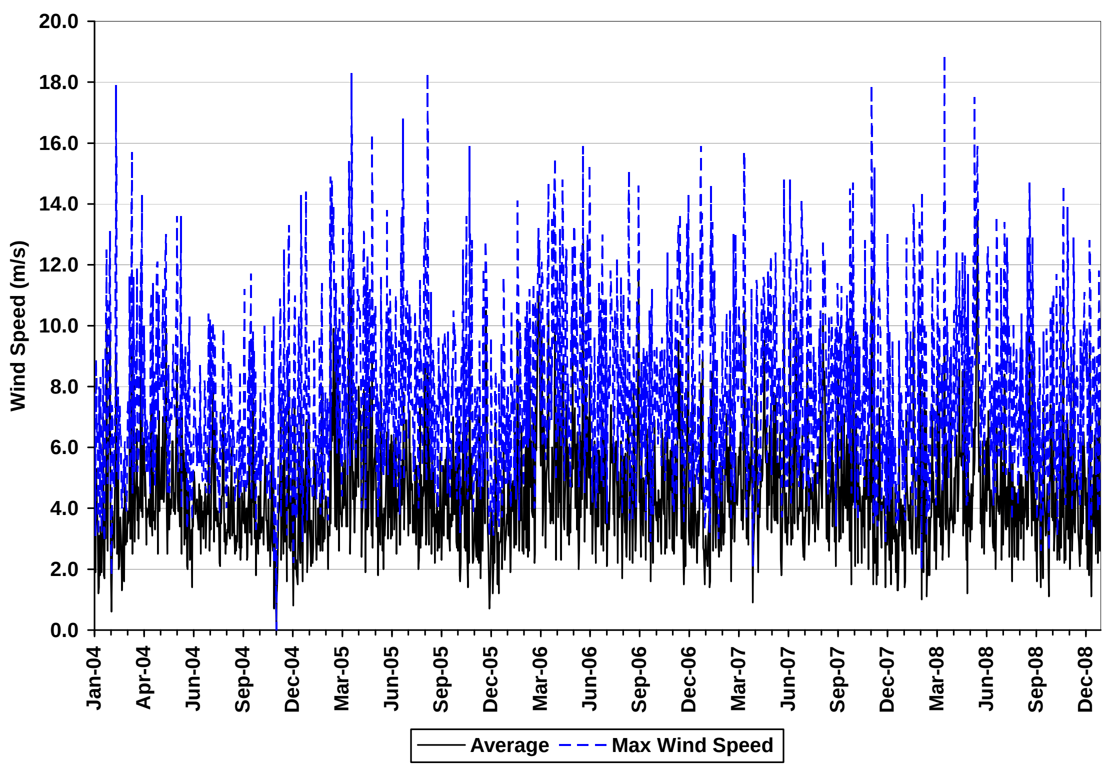

Figure 3-7. Daily average and maximum wind speed at Glasgow International Airport, Glasgow, MT.

3.3 HYDRODYNAMIC DATA

3.3.1 RESERVOIR INFLOW AND OUTFLOW

Daily discharge from the Missouri River near Landusky, MT (USGS gage no. 06115200) was input as the Missouri River branch reservoir inflow. Big Dry Creek daily discharge near Van Norman, MT (USGS gage no. 06131000) was input as the Big Dry Creek branch reservoir inflow. Daily discharge from the Musselshell River at Mosby, MT (USGS gage no. 06130500) was also input as tributary inflow to the Missouri River branch in the model. Daily inflows are plotted in Figure 3-8.

Combined hourly reservoir discharge for Fort Peck Dam was input as reservoir outflow for the Fort Peck model, and it is plotted in Figure 3-9. Milk River discharge at Nashua, MT (USGS gage no. 06174500) is also shown because along with Fort Peck discharge, it is used as an input to the downstream Missouri River water quality model.

3.3.2 RESERVOIR INFLOW AND OUTFLOW TEMPERATURE

Missouri River temperature at Landusky, MT was measured by a temperature sensor at the USGS gaging station and input into the model as daily temperature in 2005 and 2006. Data in 2004 and 2007 was not available because the sensor was not maintained, so 2005 data was used in 2004, and temperature measurements from Montana USGS dataloggers were used in 2007. Inflow temperatures are plotted in Figure 3-10.

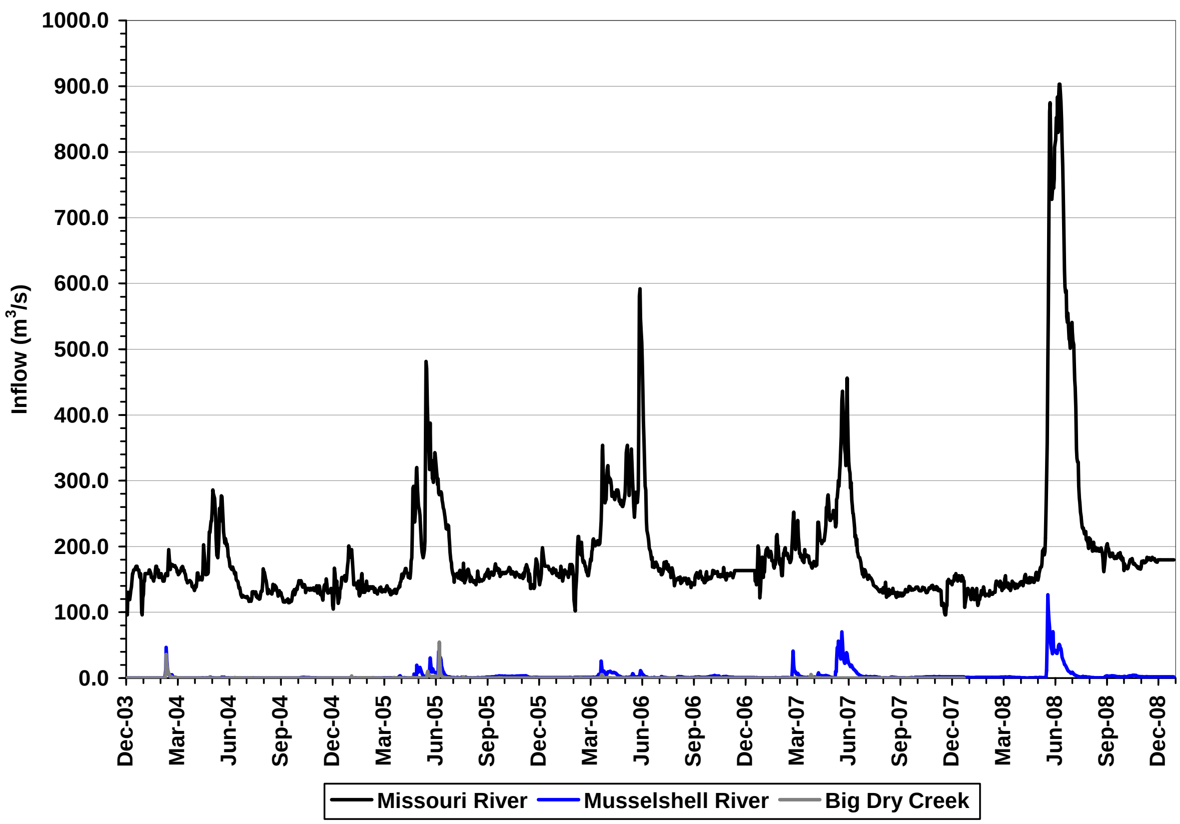

Figure 3-8. Fort Peck Reservoir inflows.

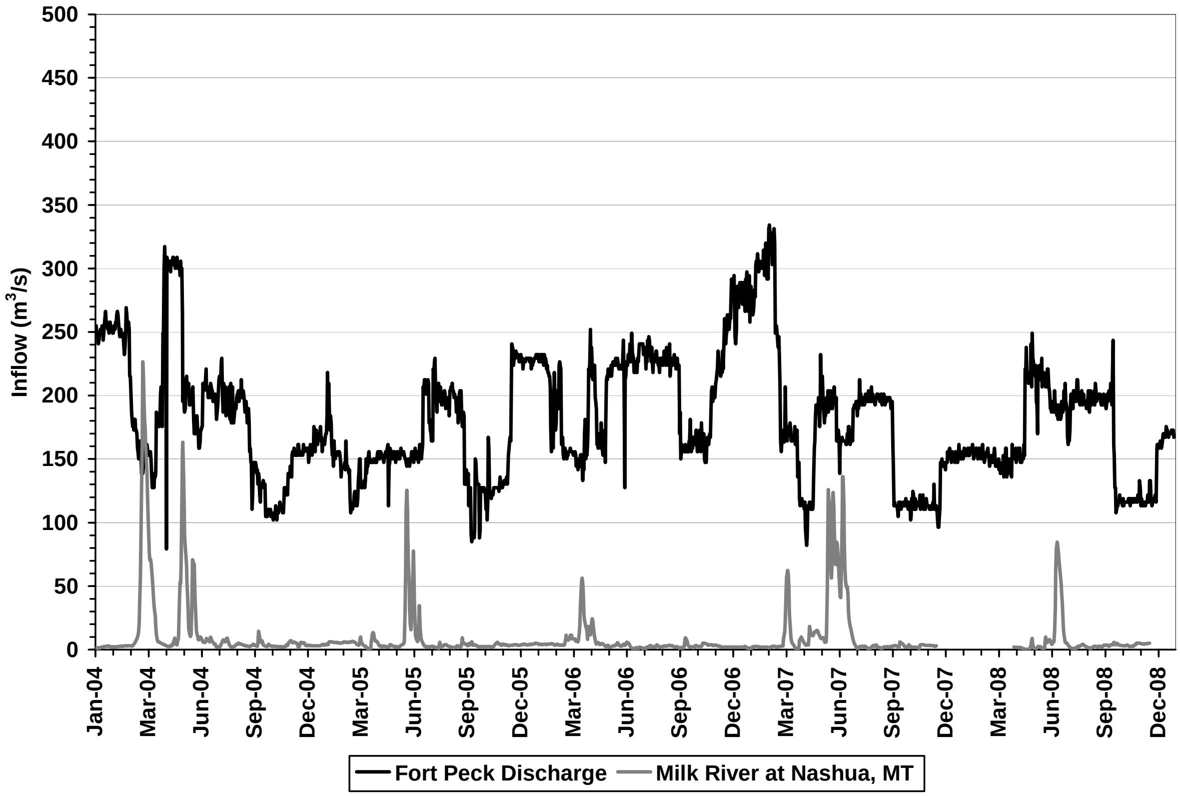

Figure 3-9. Fort Peck Dam and Milk River average daily discharge.

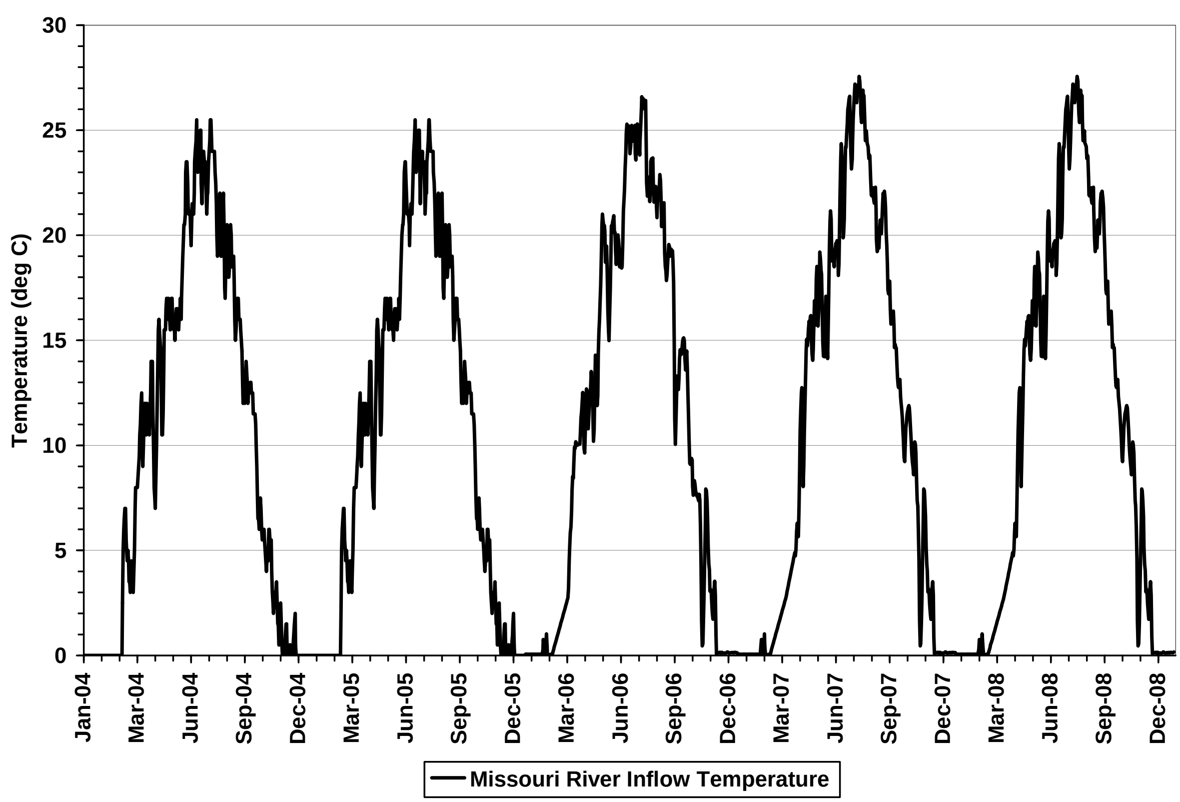

Figure 3-10. Missouri River at Landusky, MT, inflow temperature.

3.4 WATER QUALITY CONSTITUENT DATA

Locations where water quality measurements were taken are shown in Figure 3-11. Temperature profiles and water quality samples for laboratory analysis were taken only on designated sampling dates that took place one time per month from May to October.

Table 3-1. Sample points, CEQUAL-W2 segment numbers, and approximate lake kilometer.

Site Name	Alternate Name	Name	Model Segment Number	Distance from Dam (km)
FTPNFMORR1	NF1	Missouri River nr Landusky, MT		
FTPNFMSLR1	NF2	Musselshell River at Mosby, MT		
FTPPP1	OF1	Fort Peck Powerhouse		
FTPLK1772A	L1	Fort Peck Reservoir: near Dam	34	0
FTPLK1778DW	L2	For Peck Reservoir: Skunk Coulee Bay	32	10
FTPLK1789DW	L3	Fort Peck Reservoir: the Pines Rec Area	29	25
FTPLK1805DW	L4	Fort Peck Reservoir: Hell Creek Bay	24	50
FTPLKBDCA01	L5	Fort Peck Reservoir: Lower Big Dry Creek Arm	48	10
FTPLKBDCA02	L6	Fort Peck Reservoir: Rock Creek Bay	44	30

3.4.1 LAKE CONSTITUENTS

3.4.1.1 Temperature and Dissolved Oxygen Profiles

Depth-discrete lake temperature and dissolved oxygen concentrations were measured in the field at one-meter depth increments with Hydrolab instruments at four locations in the Missouri River branch and at two locations in the Big Dry Creek branch. During the intensive water quality survey from 2004 through 2006, field measurements were made at locations L1 through L6; while in 2007 and 2008 measurements were made at locations L1, L4 and L6. Temperature and dissolved oxygen profiles were assembled from the depth-discrete measurements for the purpose of reservoir temperature calibration.

3.4.1.2 Water Quality

Water quality samples were collected at the six in-pool locations at near-surface, mid-metalimnion, and near bottom water column depths. Near surface samples were collected with a plastic churn bucket, while mid-metalimnion and near bottom samples were collected with a Kemmerer sampler. A list of water quality constituents analyzed for by the Corps' contract laboratory is provided in Table 3.3 of the Water Quality Special Study Report for the Fort Peck Project (USACE, 2007).

3.4.2 INFLOW DISSOLVED OXYGEN

Dissolved oxygen measurements were taken when samples were collected at the inflow locations to the reservoir; however, since a continuous record of DO was needed at the modeled reservoir inlet, it was approximated as the saturated DO concentration using an empirical equation. The equation (Equation 1) provided by the Environmental Laboratory of ERDC approximates DO concentrations in milligrams per liter of water (mg/L) as a function of water temperature (*T*) in Kelvin (K) and elevation (*z*) in kilometers (km). Measured and assumed water temperatures were used in the approximation, and the resulting DO concentrations are shown in Figure 3-12. Computed DO concentrations were within 5.0 to 10.0% of measured DO concentrations.

$$DO = (1 - 0.1148z)\exp\left(-139.3441 + \frac{1.58x10^5}{T} - \frac{6.64x10^7}{T^2} + \frac{1.24x10^{10}}{T^3} - \frac{8.62x10^{11}}{T^4}\right) \quad \text{(Equation 1)}$$

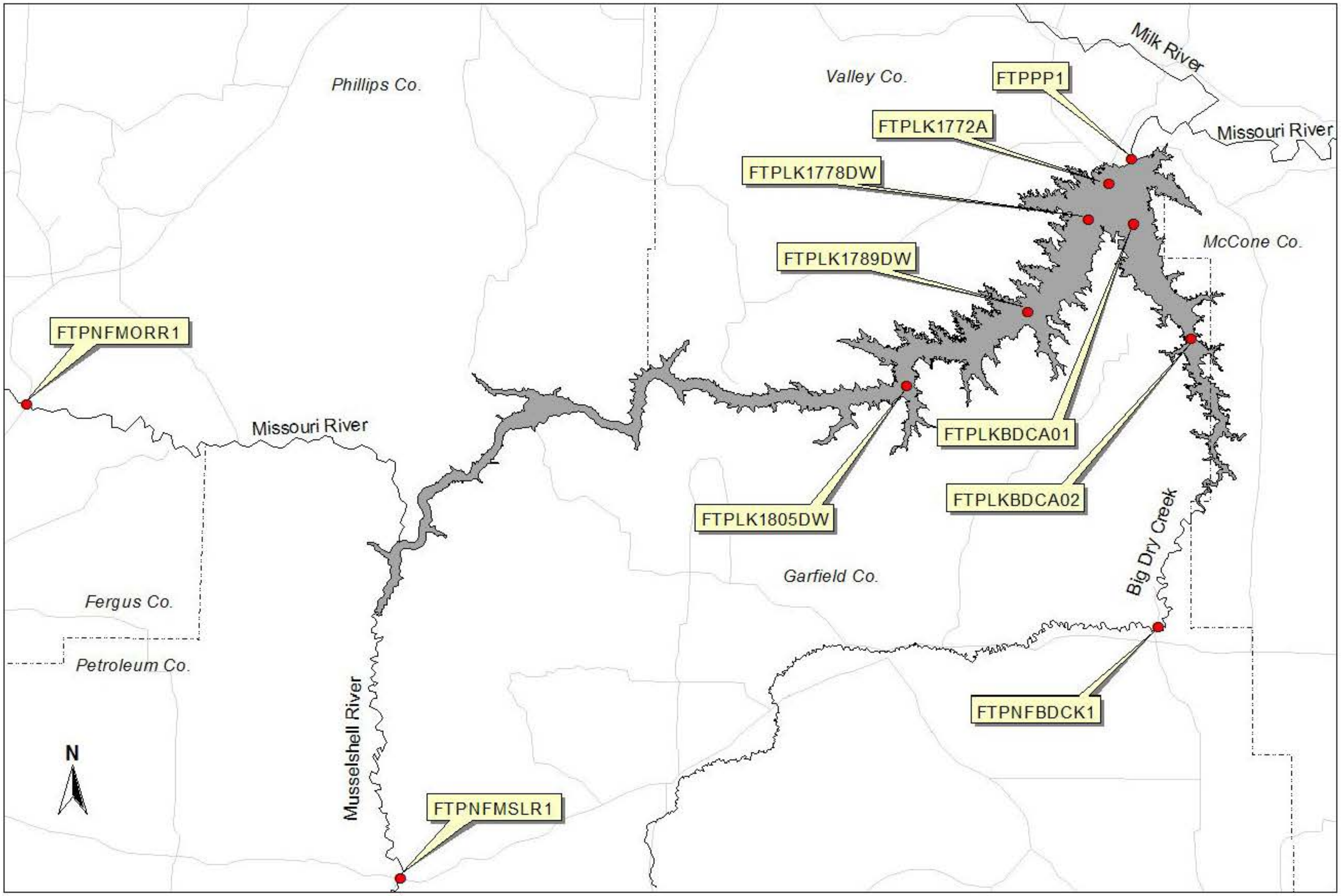

Figure 3-11. District water quality monitoring locations at Fort Peck Reservoir during the period of 2004 through 2008.

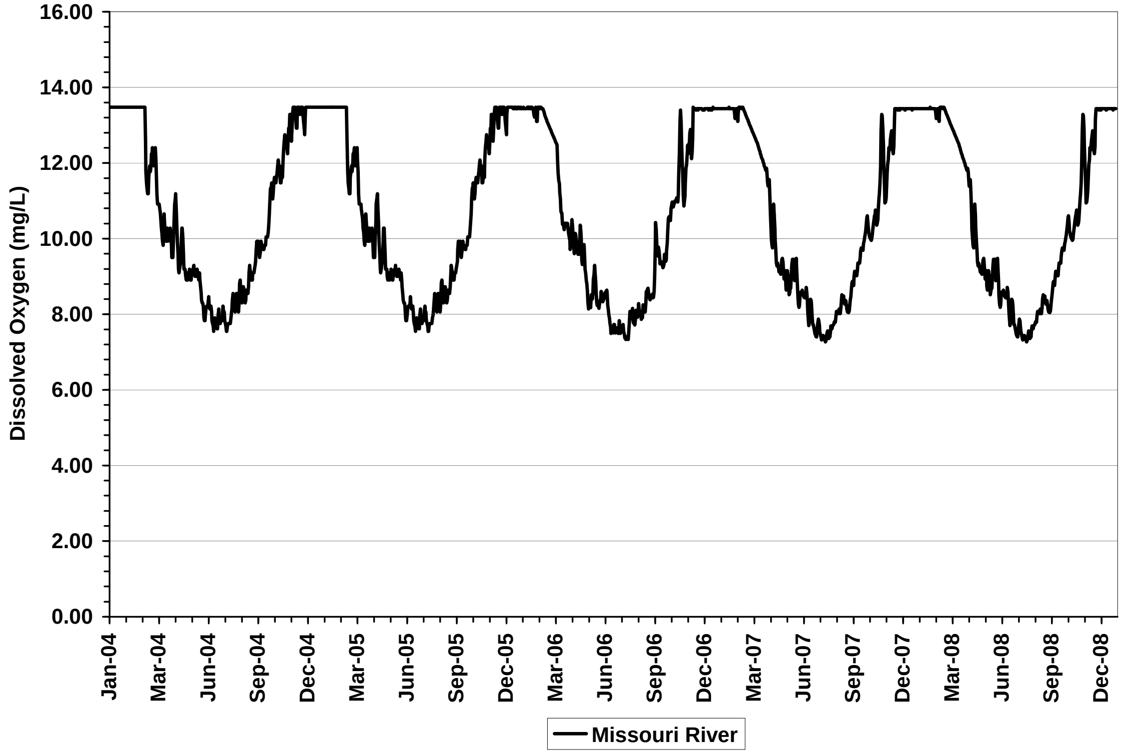

Figure 3-12. Dissolved oxygen saturation concentration in the Missouri River at Landusky, MT.

3.4.3 INFLOW CONSTITUENTS

Water quality samples were taken during the survey period at two inflow locations: 1) FTPNFMORR1 on the Missouri River near Landusky, MT, and 2) FTPNFMSLR1 on the Musselshell River at Mosby, MT. Water samples were taken three to six times per year at Landusky, MT, and about one to three times per year at Mosby, MT. Analyzed constituent concentrations were entered into the model as branch and tributary inflow concentrations. The constituent concentrations provided the model included total dissolved solids, suspended solids, phosphate phosphorus, ammonium, nitrate/nitrite, dissolved silica, particulate silica, total iron, labile and refractory dissolved organic matter, labile and refractory particulate organic matter, algae, DO, and alkalinity.

Dissolved and particulate organic matter was estimated from total organic carbon concentrations at an organic carbon to organic matter ratio of 0.45. Furthermore through model calibration, 90% of organic matter was assumed dissolved and 10% was assumed particulate, and 10% of organic matter was assumed labile and 90% was assumed refractory.

Since a continuous daily inflow constituent record was not possible, constituent concentrations were assumed at the beginning of each month in each simulation year along with the actual concentrations on the sampling dates. In the absence of sampled constituent concentrations for the Musselshell River and Big Dry Creek, Missouri River concentrations were used. Streamflow from the Musselshell River and Big Dry Creek was a very small percentage of total inflow, therefore the mass of water quality constituents had a limited impact on reservoir water quality.

4 WATER TEMPERATURE & CONSTITUENT CALIBRATION

Reservoir hydrodynamics were calibrated by running a water balance routine to match the simulated reservoir inflow-outflow-storage to the observed inflow-outflow-storage. Reservoir temperatures and dissolved oxygen were calibrated at three locations where temperature profiles were measured throughout the observing years. In addition powerhouse release temperatures and dissolved oxygen concentrations were compared to observations as an additional level of model calibration .

4.1 POOL ELEVATION

The water balance routine computes the difference in observed reservoir storage and simulated reservoir storage by feeding the program observed and simulated pool elevations, then computing reservoir inflow or outflow needed to balance the storage. The hydrodynamic calibration is completed when the water balance inflows and outflows are added back to the reservoir in a subsequent simulation to attain a balanced pool. The resulting pool elevations are shown in Figure 4-1.

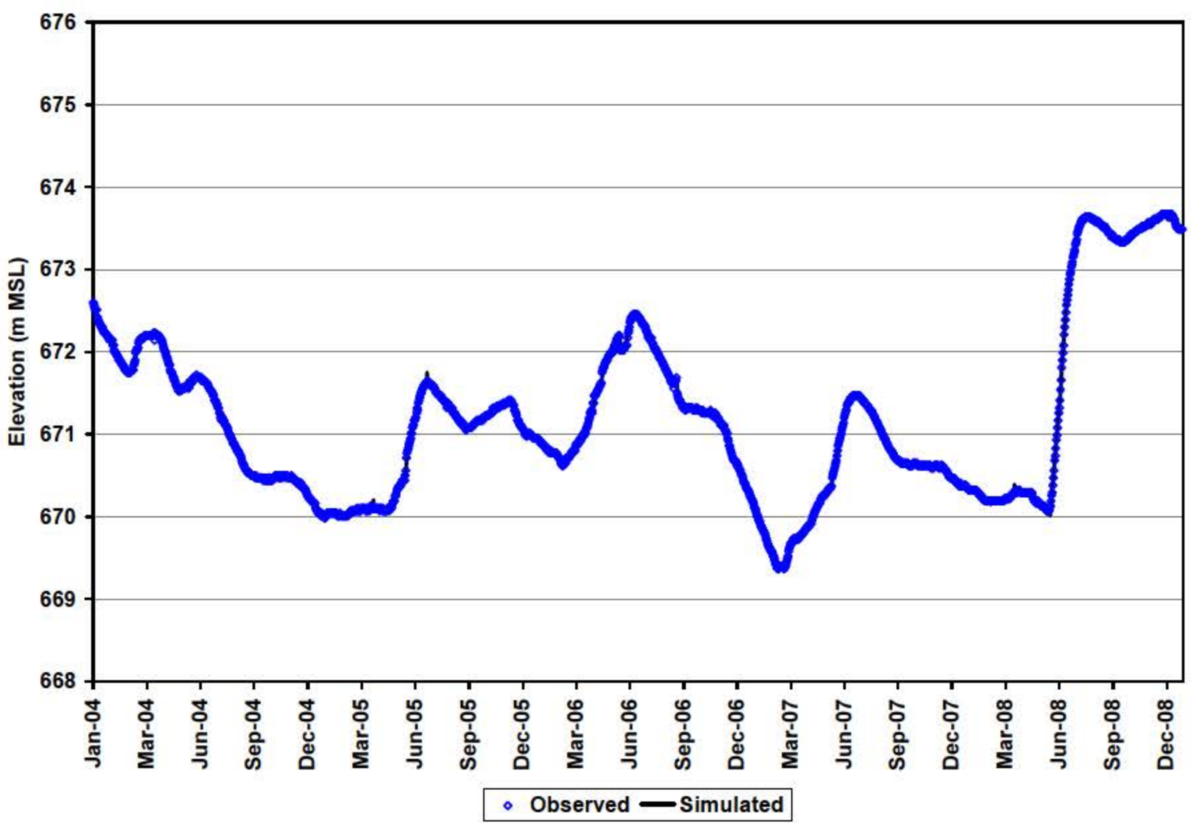

Figure 4-1. Observed and simulated Fort Peck Reservoir pool elevation for 2004 through 2008.

4.2 RESERVOIR POOL

4.2.1 TEMPERATURE

Simulated reservoir temperatures were calibrated to measured temperature profiles at reservoir locations L1 through L6 in 2004, 2005 and 2006, and at locations L1, L4 and L6 in 2007 and 2008. In order to maintain consistency in displaying model results in this report, calibration plots from reservoir locations L1, L4 and L6 are presented in this report. Simulated temperature profiles from the calibrated model are plotted with observed temperature profiles in Figures 9-1 through 9-15.

Factors that affected temperature calibrations the most included wind speed, wind sheltering coefficients (WSC) and solar radiation as determined by cloud cover specified in the meteorology file. In all simulations WSC's were generally set at 0.9 with some seasonal variation at times when the reservoir required more or less vertical mixing to achieve a temperature profile similar to the observed temperature. Cloud coefficients (CLOUD) were increased overall by a value of two (2) because existing coefficients allowed too much solar radiation to penetrate the water surface resulting in higher than actual lake profile temperatures.

4.2.2 DISSOLVED OXYGEN

Simulated DO concentration profiles from the calibrated model are plotted with observed DO concentration profiles in Figures 9-16 through 9-30.

Factors that affected DO calibrations greatest included initial reservoir concentrations of labile dissolved and particulate organic matter, inflow concentrations of labile dissolved and particulate organic matter, algal biomass respiration and decomposition, and sediment oxygen demand (SOD). Labile and refractory percentages of total organic matter are described in Section 2.5.5 of this report. Inflow water concentrations containing 10% of the organic matter in the particulate phase was essential to simulating observed DO concentrations. Algal algorithms were adjusted in order generate more algal biomass in the epilimnion causing a greater demand for oxygen during respiration and biomass degradation. Furthermore first- and second-order SOD functions were adjusted slightly to improve the DO calibration in the hypolimnion.

4.2.3 CALIBRATION ACCURACY

Statistically the best temperature calibrations were achieved from 2004 through 2006 and 2008, while 2007 was the least accurate (Table 4-1). Absolute errors ranged from 0.53 to 1.38^{o}C with an average of 0.85^{o}C, while root-mean-square (RMS) errors ranged from 0.66 to 1.61^{o}C with an average of 1.02^{o}C (Table 4-1). Plots showing simulated versus observed temperature profiles at lake locations L1, L4 and L6 are provided in the supplemental Figures 9-1 to 9-15 at the end of the report.

Statistically the best DO calibration with the lowest absolute and RMS errors was achieved from 2004 through 2006 and 2008 while 2007 was the least accurate calibration based on computed errors (Table 4-1). The average absolute and RMS errors were 0.49 mg/L and 0.57 mg/L, respectively. Plots showing simulated versus observed DO profiles at lake locations L1, L4 and L6 are provided in the supplemental Figures 9-16 to 9-30 at the end of the report.

Table 4-1. Average annual absolute and root mean square errors between measured and simulated reservoir temperatures and dissolved oxygen concentrations over three reservoir locations (L1, L4, & L6).

Year	Temperature (^{o}C)		Dissolved Oxygen (mg/L)	
	Absolute	Root-Mean Square	Absolute	Root-Mean Square
2004	0.53	0.66	0.37	0.42
2005	0.83	1.02	0.48	0.56
2006	0.80	0.92	0.48	0.52
2007	1.38	1.61	0.61	0.68
2008	0.67	0.82	0.22	0.27
Average	0.85	1.02	0.49	0.57

4.3 RESERVOIR OUTFLOW

A monitoring station was established in the Fort Peck powerplant that draws water off the plant's raw water supply line. The monitoring station included a Hydrolab which measured and logged temperature and DO concentrations on an hourly basis. The water in the raw water supply line is believed to be representative of the power releases from the dam. The CE-QUAL-W2 model produces simulated output for combined powerhouse releases, temperatures, and constituent concentrations. The simulated and observed temperatures and dissolved oxygen concentrations are compared as an additional means of calibration.

4.3.1 TEMPERATURE

Combined simulated outflow temperatures, on a six-hour time step, are plotted against hourly observed temperatures in Figure 4-2. Absolute and root-mean square errors between observed and simulated outflow temperatures are provided in Table 4-2. In general the model produced close-fitting release temperatures when compared to observed temperatures.

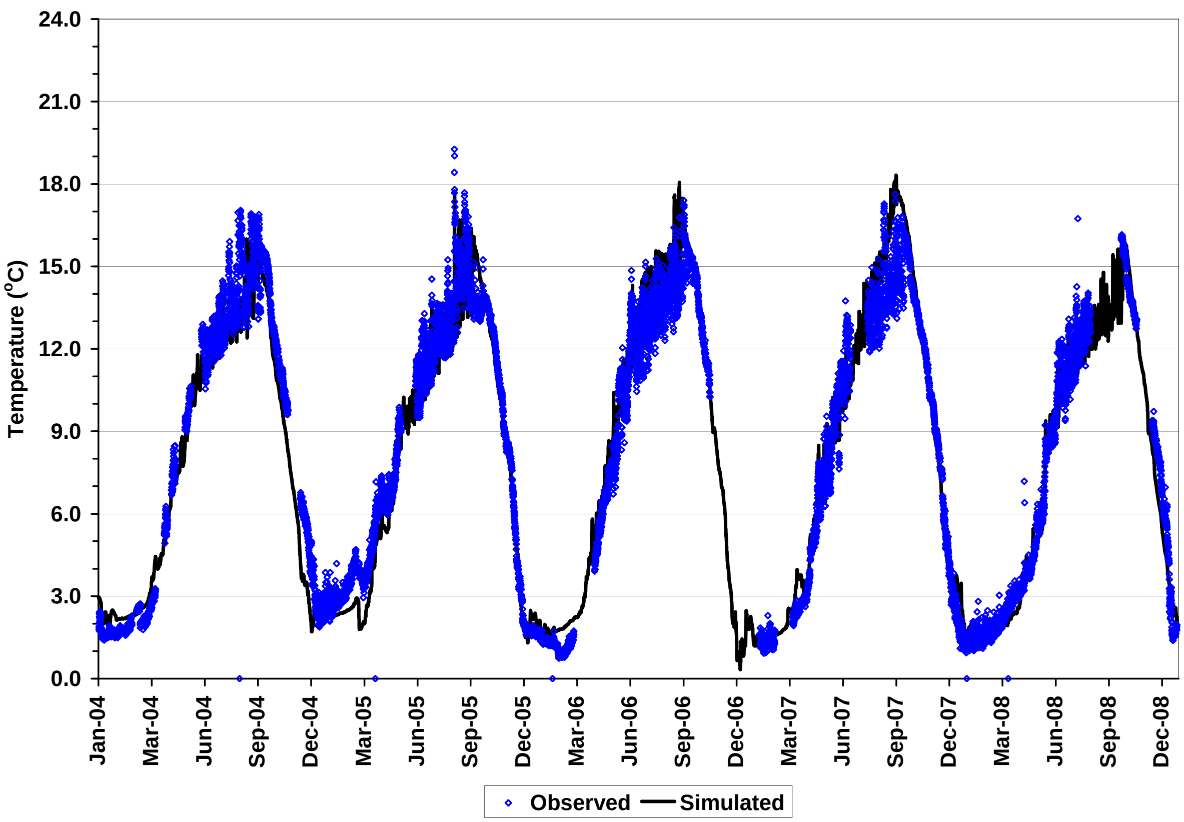

Figure 4-2. Simulated and observed Fort Peck powerhouse release temperatures.

4.3.2 DISSOLVED OXYGEN

Combined simulated outflow DO concentrations are plotted against hourly observed DO in Figure 4-3. While the simulations predict the shape of the reservoir outflow DO concentrations, the simulations do not predict the peak or the valley concentrations well. The simulations also miss the DO concentration timing. Absolute and root-mean square errors between observed and simulated outflow dissolved oxygen concentrations are provided in Table 4-2.

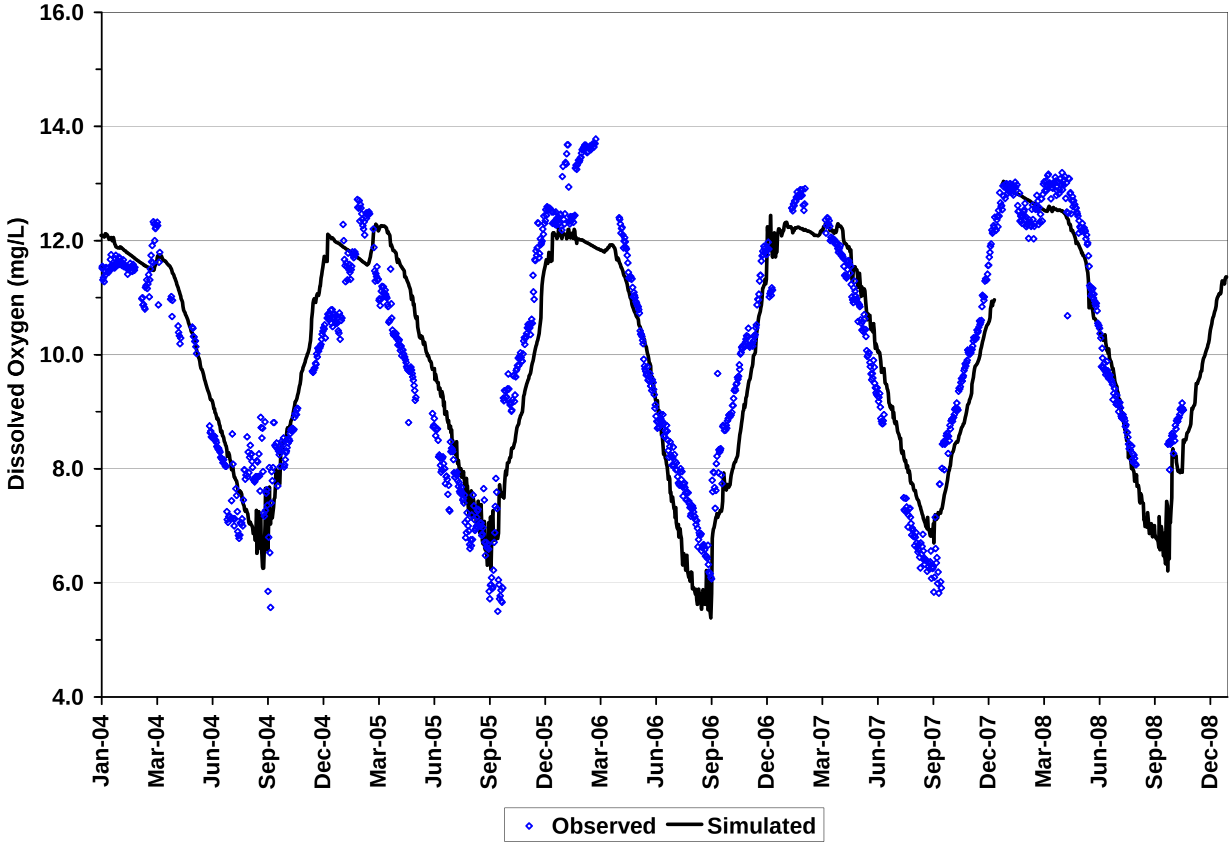

Figure 4-3. Simulated and observed Fort Peck powerhouse dissolved oxygen concentrations.

4.3.3 CALIBRATION ACCURACY

Statistically the best outflow temperature calibrations were achieved in 2005, 2006 and 2008 while 2004 and 2007 were the least accurate (Table 4-2). Absolute (arithmetic) errors ranged from -0.33 to 0.81°C with an overall average error of 0.52°C, while root-mean-square (RMS) errors ranged from 0.74 to 1.15°C with an average of 1.01°C.

Statistically the best outflow DO calibration with the lowest absolute and RMS errors was achieved in 2008 followed by 2006 and 2007, and finally 2005 and 2004 (Table 4-2). The average absolute and RMS errors were 0.15 mg/L and 1.80 mg/L, respectively.

Table 4-2. Average annual absolute and root mean square errors between measured and simulated outflow temperatures and dissolved oxygen concentrations.

Year	Temperature (^oC)		Dissolved Oxygen (mg/L)	
	Absolute	Root-Mean Square	Absolute	Root-Mean Square
2004	-0.33	1.15	0.71	2.53
2005	0.77	0.99	0.61	2.22
2006	0.74	0.97	-0.63	1.30
2007	0.81	1.14	0.23	1.77
2008	0.57	0.74	-0.18	0.49
Average	0.52	1.01	0.15	1.80

5 WATER QUALITY ASSESSMENT UNDER EXISTING CONDITIONS

Fort Peck Lake maintains a "two-story" fishery that is comprised of warmwater and coldwater species. The ability of the reservoir to maintain a "two-story" fishery is due to its thermal stratification in the summer into a colder bottom region and a warmer surface region. Warmwater species present in the reservoir that are recreationally important include walleye (*Sander vitreus*), sauger (*Sander canadensis*), northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieu*), channel catfish (*Ictalurus punctatus)*, and yellow perch (*Perca flavescens*). Coldwater species of recreational importance are the Chinook salmon (*Oncorhynchus tshawytscha*) and lake trout (*Salvelinus namaycush*). Chinook salmon are maintained in the reservoir through regular stocking and lake trout naturally reproduce. Another coldwater species present in Fort Peck Lake is the lake cisco (*Coregonus artedi*) which is an important forage fish that is utilized extensively by all the recreational species.

The State of Montana has assigned Fort Peck Lake a B-3 classification in the State's water quality standards. As such, the reservoir is to be maintained suitable for drinking, culinary, and food processing purposes, after conventional treatment; bathing, swimming, and recreation; growth and propagation of non-salmonid fishes and associated aquatic life, waterfowl, and furbearers; and agricultural and industrial water supply. Although a coldwater aquatic life use is not assigned to Fort Peck Lake, a coldwater fishery currently exists in the reservoir and "coldwater habitat" would seemingly be protected under the anti-degradation provisions of the State of Montana's water quality standards and the Federal Clean Water Act (CWA). The numeric water temperature and dissolved oxygen criteria identified in Montana's water quality standards to protect "B-2" coldwater habitat (CWH) are, respectively, 19.4°C and 5 mg/l.

One of the few remaining populations of federally-designated, endangered pallid sturgeon (*Scaphirhynchus albus*) occurs in the Missouri River downstream of Fort Peck Dam. As such, this reach of the Missouri River has been identified as a priority recovery area for the pallid sturgeon. It is believed that the building and operation of Fort Peck Dam and Reservoir have adversely impacted the pallid sturgeon in this reach of the Missouri River by regulating flows, lowering water temperatures, reducing sediment and nutrient transport, and increasing water clarity. Water temperature is believed to be a controlling factor on the pallid sturgeon in this reach of the Missouri River in regards to spawning cues and larval survival during the summer. Because Fort Peck Dam has a deepwater withdrawal from the reservoir, water temperature in the Missouri River downstream of the dam are appreciably colder than "pre-dam" conditions. A water temperature of around 18°C (64.4°F) is believed necessary to initiate a spawning response in pallid sturgeon. Additionally, a dramatic decline in water temperatures after spawning can affect larval pallid sturgeon development and likely adversely affect the production and availability of suitable forage (i.e., plankton and other invertebrate species) for the juvenile pallid sturgeon throughout the summer. Low water temperatures may also induce mortality in young pallid sturgeon. With this in mind, the 2003 amended Missouri River Biological Opinion identified a late-spring/early-summer water temperature of 18°C in the Missouri River at Frazer Rapids (approximately 25 miles downstream of Fort Peck Dam) as critical for pallid sturgeon spawning and recruitment in this reach of the river (USFWS, 2003).

Water quality was assessed based on reservoir temperatures and dissolved oxygen concentrations with respect to CWH criteria and the downstream target. Temperature and dissolved oxygen trends are shown in plots of temperature versus time at the Fort Peck Dam intake portal crest elevation of 638.6 m (2095.0 ft) near the dam. It is assumed in this assessment that water released from the reservoir through the intake is drawn from this elevation.

5.1 TEMPERATURE TRENDS

Lake temperature at the intake portal crest elevation of 638.6 m (2095.0 ft) increases from near $5^{o}C$ on May 1 to its peak between 14.0 and $17.0^{o}C$ in mid- to late-September (Figure 5-1). Temperatures in all four years do not reach the $19.4^{o}C$ maximum limit for coldwater habitat during the simulations. Additionally, the temperature of water that would likely be released to the Missouri River does not reach the $18.0^{o}C$ temperature target desired at Frazer Rapids, MT, but it is near $17\,^{o}C$ in 2007.

Among individual simulation years, 2004 water temperatures were the coldest seemingly because 2004 was the coolest of the four years meteorologically. Furthermore, the seasonal runoff volume was lowest, so the lake received the least amount of thermal energy through inflows. In 2007 the lake reached the warmest late summer temperatures seemingly due to low pool levels (Figure 5-1) caused by the drought and warm meteorological temperatures.

5.2 DISSOLVED OXYGEN TRENDS

Dissolved oxygen (DO) concentration trends at the intake portal crest elevation of 638.6 m (2095.0 ft) were similar in all years (Figure 5-2). Beginning on May 1 concentrations ranged from 11.0 to 12.0 mg/L and gradually decreased to the lowest levels between 6.0 and 8.0 mg/L in September, at which time DO degradation is greatest due to organic matter decay within the water column. DO minimum concentrations begin increasing after lake turnover occurs from late September to early October.

Differences in DO trends among simulations years are minor and are complicated by the presence of calibration error in the temperature profiles, especially in the deepest portions of the reservoir. In the deepest portions of the reservoir water column, DO concentrations are most sensitive to sediment oxygen demand and organic matter decay which are difficult processes to simulate.

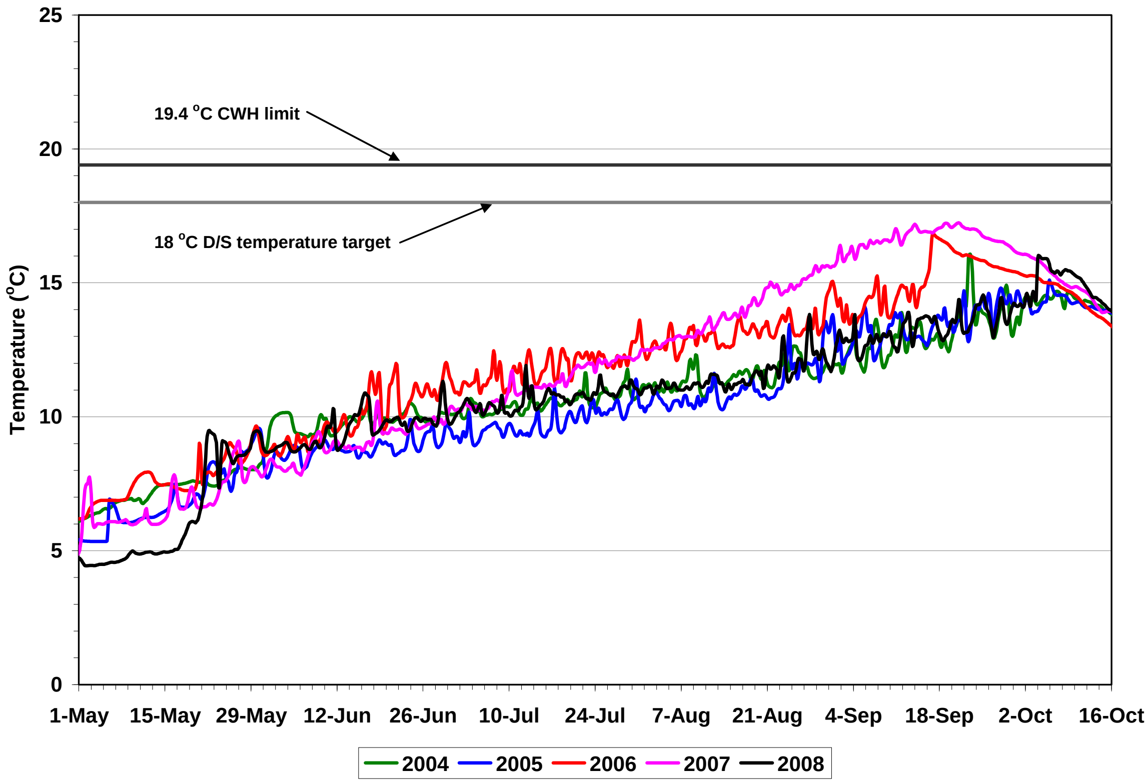

Figure 5-1. Simulated water temperatures at the crest of the intake portal elevation 638.6 m (2095.0 ft) near Fort Peck Dam.

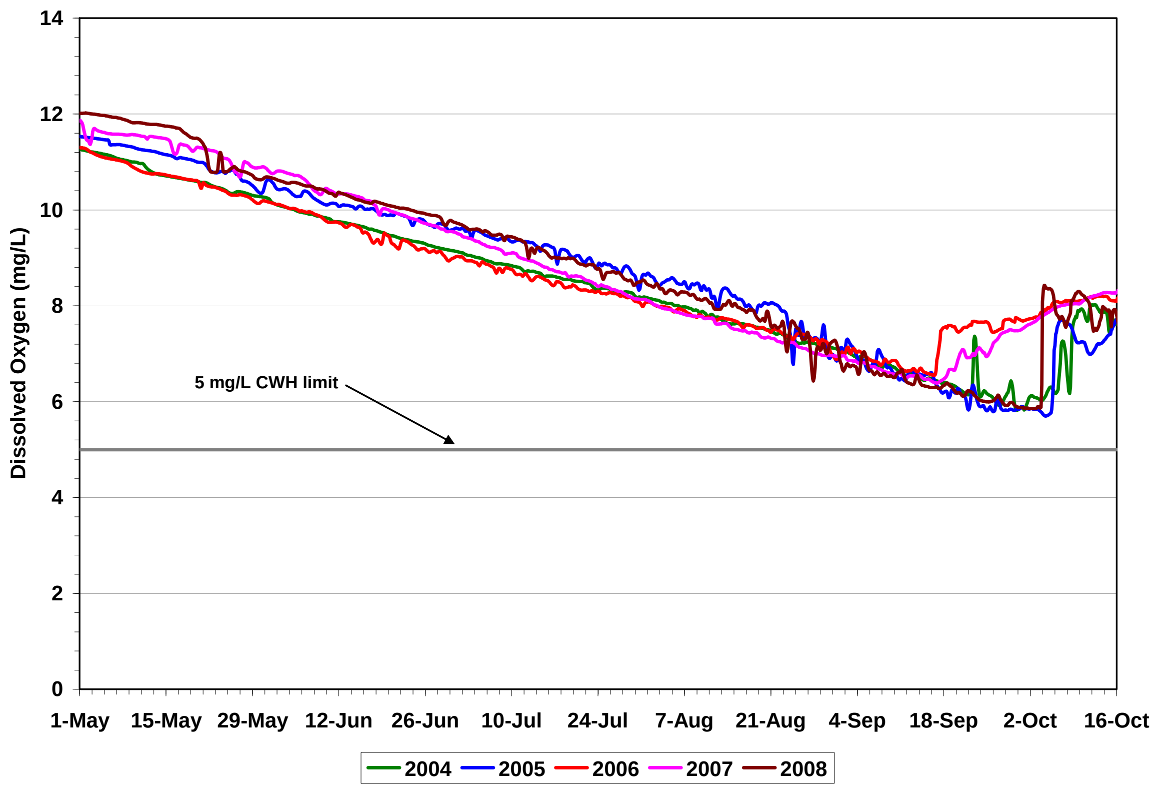

Figure 5-2. Simulated dissolved oxygen concentrations at the crest of the intake portal elevation 638.6 m (2095.0 ft) near Fort Peck Dam.

5.3 COLDWATER HABITAT

Coldwater habitat (CWH) is defined as water in the reservoir that meets the minimum DO concentration of 5 mg/L and a maximum temperature of 15 to 19.4°C, and is therefore suitable habitat for certain species of coldwater fish. Optimal CWH meets the minimum DO concentration requirement and the more stringent maximum temperature of 15°C, while total CWH must meet the maximum temperature of 19.4°C. CWH was estimated in Fort Peck Lake based on measured water temperature and dissolved oxygen depth profiles applied to zone volumes for each measurement location.

The calibrated CE-QUAL-W2 model was used to estimate CWH by summing the volume of water that met both the optimal and total CWH temperature and DO criteria. CWH is expressed in units of million acre feet (MAF) in this report because acre-feet is the conventional unit for reporting reservoir storage volume.

5.3.1 ELEVATION OF COLDWATER HABITAT CRITERIA

The simulated elevations of constant temperature and DO concentration criteria for optimal CWH for the 1st and median day of each month in 2004, 2005, 2006, 2007 and 2008 are plotted in Figure 5-3. In this plot the 15°C isotherms all progressively decline in elevation during the year as warmer water above the isotherm is driven deeper into the reservoir and colder water below the isotherm is warmed and released through low level withdrawals. At the same time 5 mg/L DO isopleths rise in elevation beginning in early August indicating a decline in DO concentrations especially near the bottom of the reservoir. A similar plot depicting the 19.4°C isotherms is shown in Figure 5-4. The difference in elevation between the isotherms and isopleths represents the thickness of CWH water at location L1.

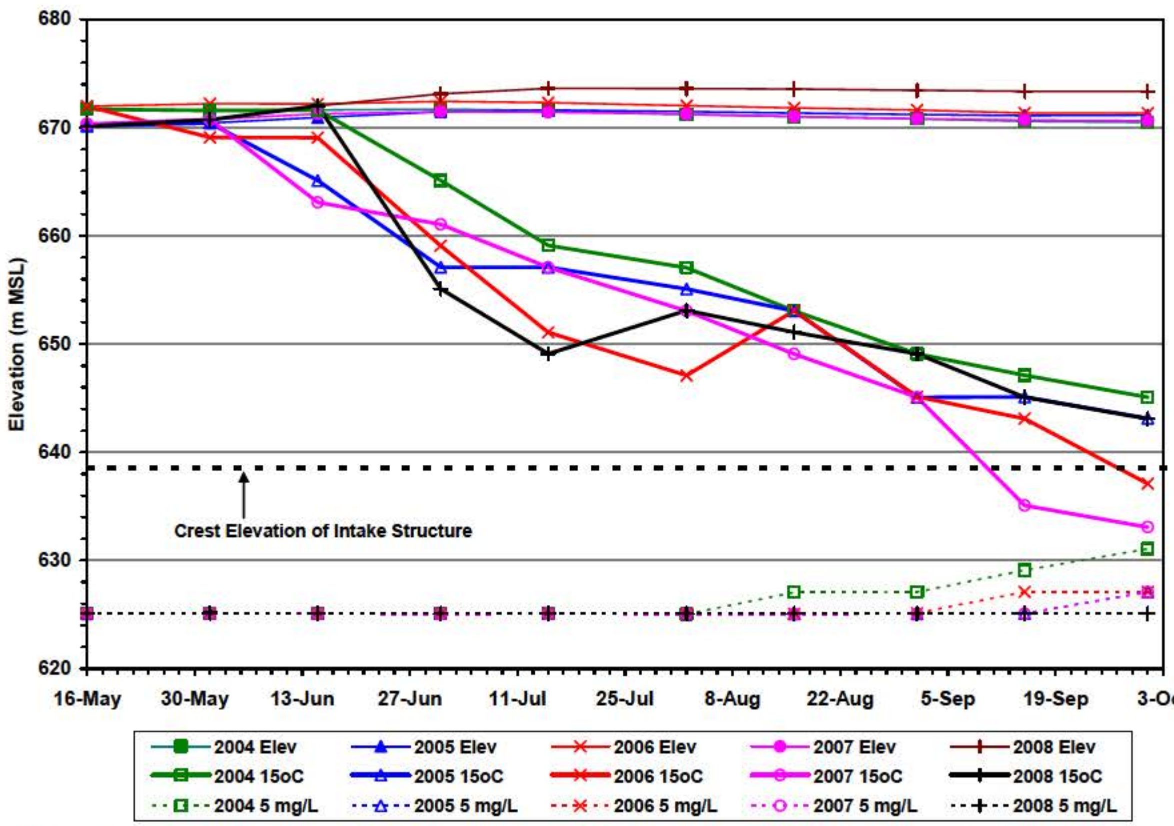

Figure 5-3. Elevation of simulated lake surface, 15°C water temperature, and 5 mg/L dissolved oxygen concentration isopleths by year for station L1.

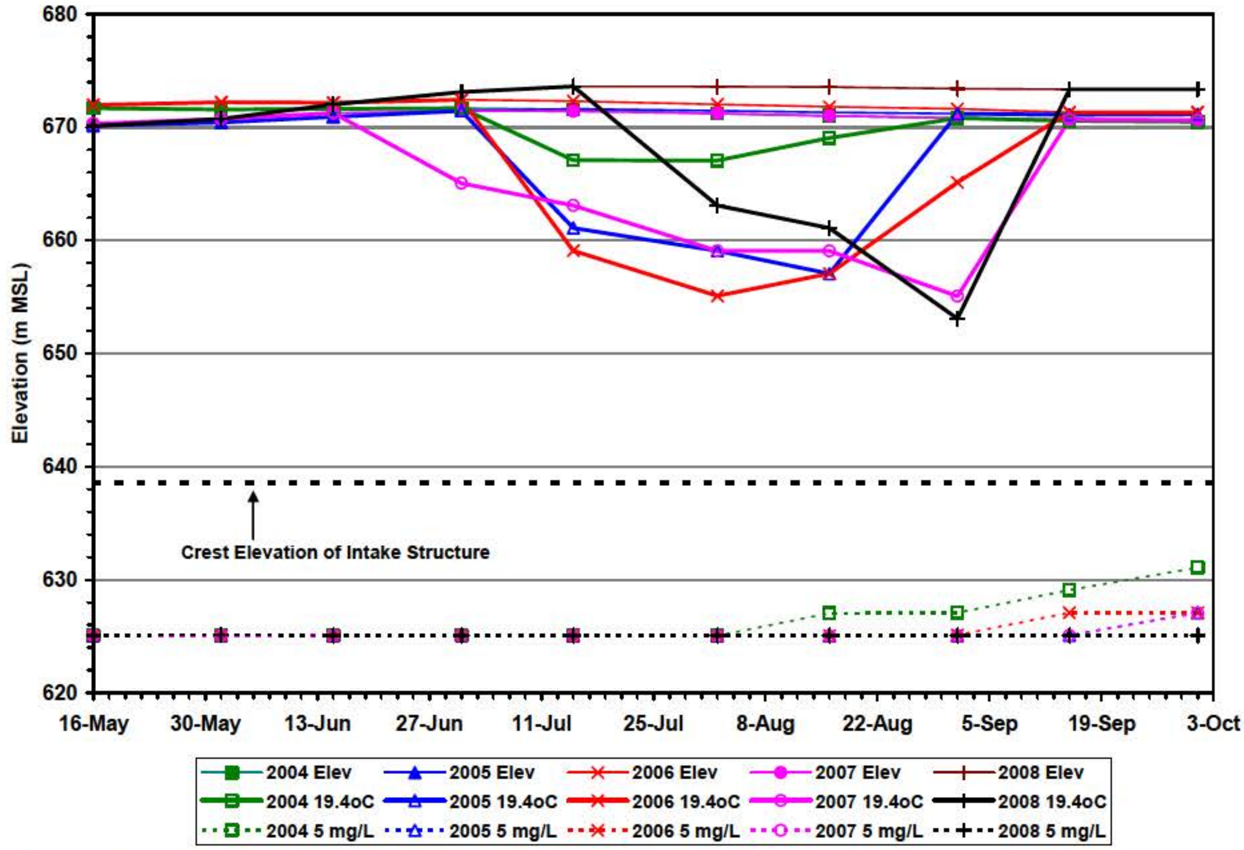

Figure 5-4. Elevation of simulated lake surface, 19.4°C water temperature, and 5 mg/L dissolved oxygen concentration isopleths by year for station L1.

5.3.2 COLDWATER HABITAT VOLUME

Both marginal and optimal CWH volumes were computed from the 2004 – 2008 simulations using the Animation and Graphics Portfolio Manager (AGPM) for CE-QUAL-W2. Estimated CWH volumes were assumed to be accurate because they were based on direct measurements of temperature and DO concentrations performed during the 2004 through 2008 water quality survey. Computed CWH volumes are plotted against estimated CWH volumes in Figures 5-5 through 5-9.

The fit of simulated CWH versus survey estimated CWH is relatively close in years 2004 through and 2006. Coldwater habitat based on measured temperature and DO was not estimated in 2007 and 2008. The model has the potential to accurately simulate CWH during times when temperature and DO measurements are not available or to evaluate the impact of water quality measures used to manage CWH.

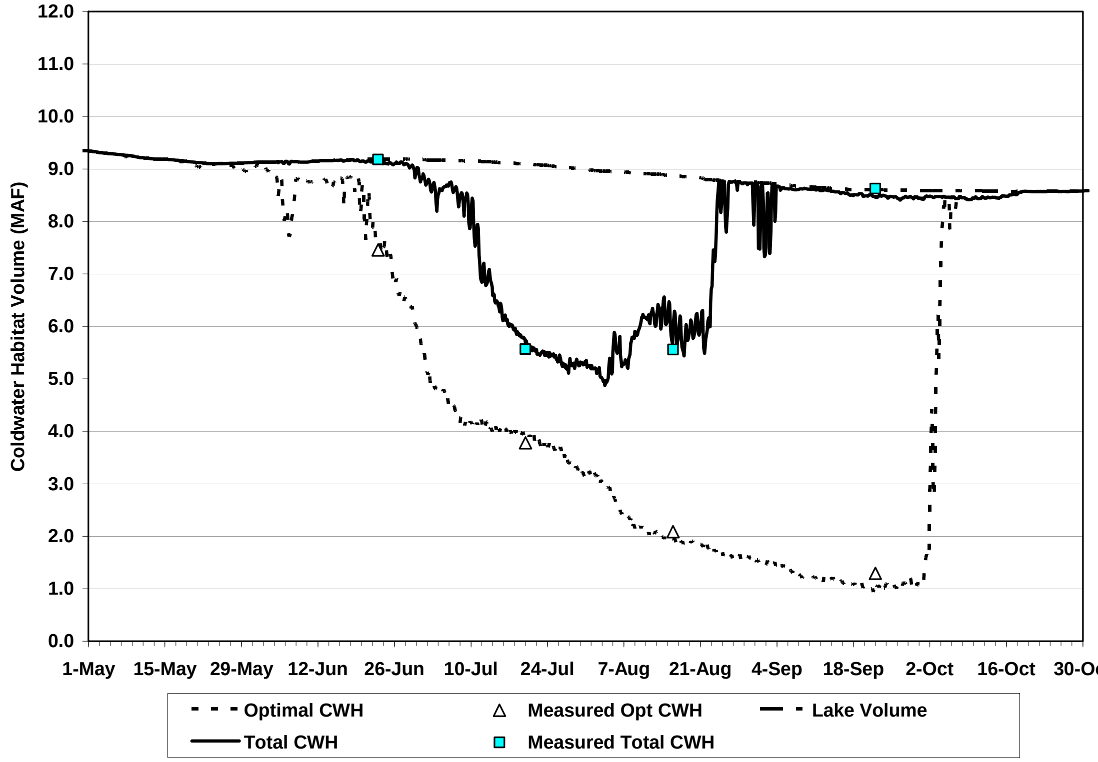

Figure 5-5. Simulated and estimated optimal and total CWH (million acre-feet) in Fort Peck Lake during 2004.

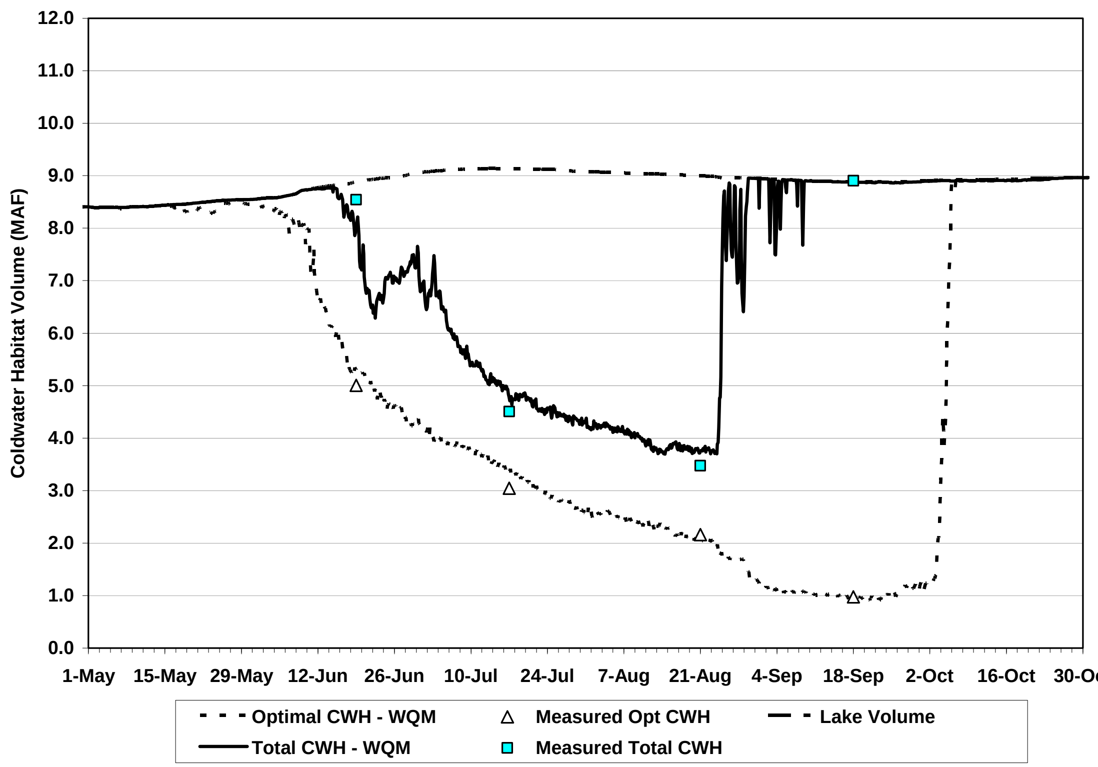

Figure 5-6. Simulated and estimated optimal and total CWH (million acre-feet) in Fort Peck Lake during 2005.

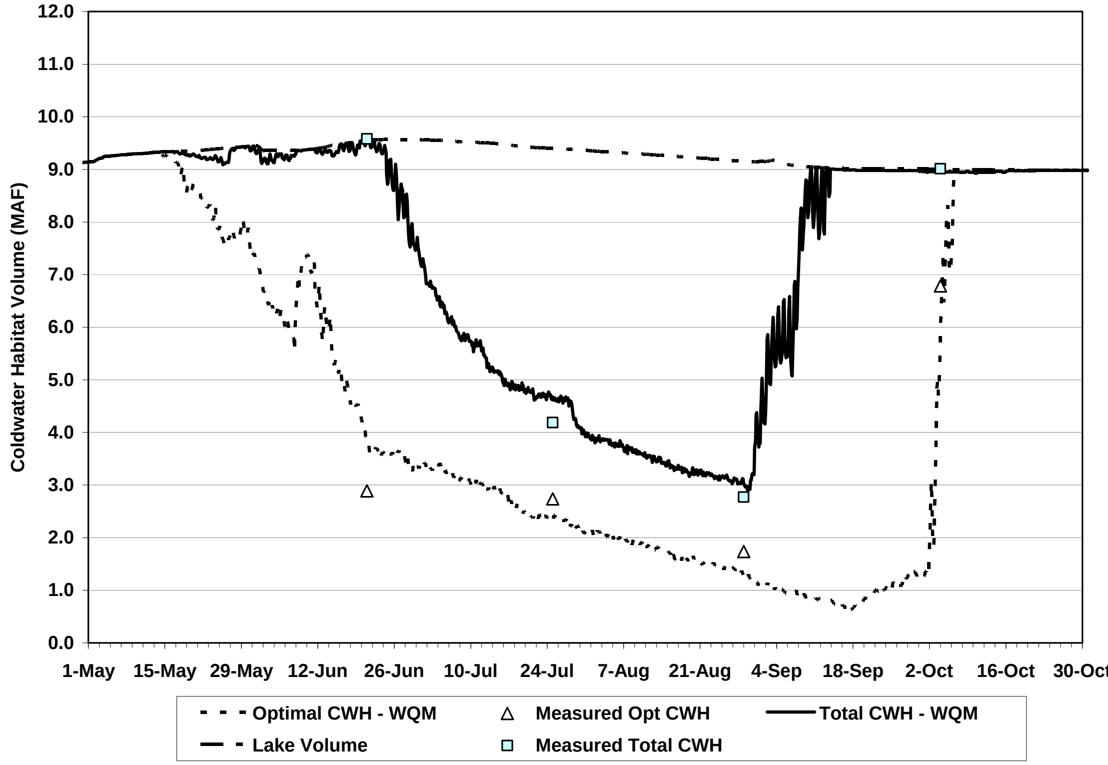

Figure 5-7. Simulated and estimated optimal and total CWH (million acre-feet) in Fort Peck Lake during 2006.

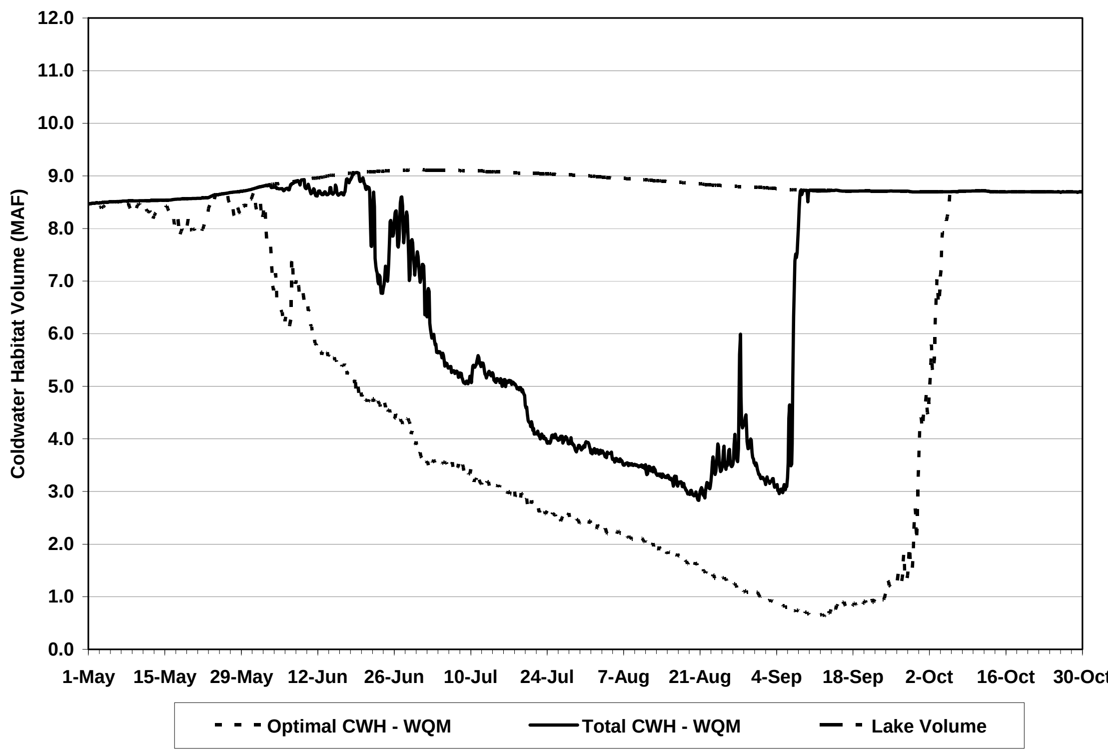

Figure 5-8. Simulated optimal and total CWH (million acre-feet) in Fort Peck Lake during 2007.

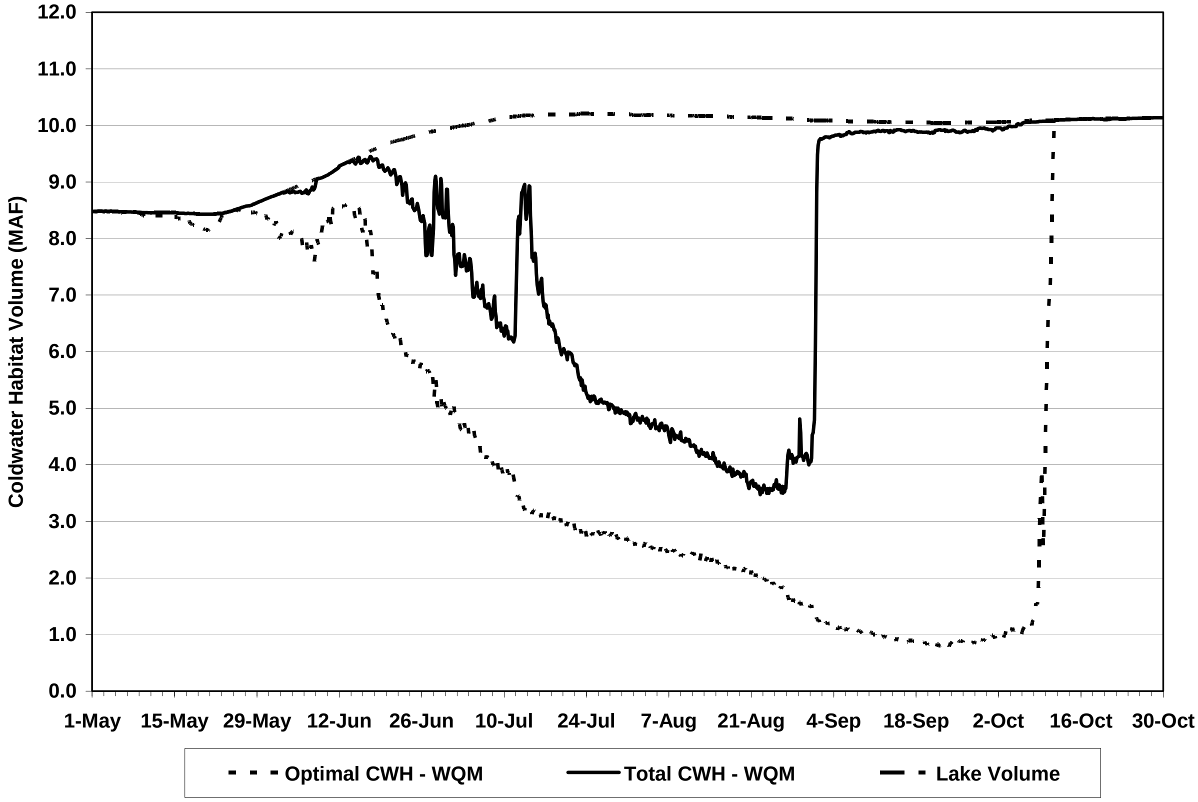

Figure 5-9. Simulated optimal and total CWH (million acre-feet) in Fort Peck Lake during 2008.

6 ASSESSMENT OF HYPOTHETICAL HIGH-LEVEL RESERVOIR WITHDRAWAL

6.1 HYPOTHETICAL HIGH-LEVEL RESERVOIR WITHDRAWAL

The US Fish and Wildlife Service's (USFWS) Biological Opinion of the Operation of the Missouri River Main Stem Reservoir System recommended temperature enhancements downstream of Fort Peck Dam to improve environmental conditions for the endangered pallid sturgeon. The USFWS temperature target in the Missouri River at Frazer Rapids, MT, approximately 26.5 miles downstream of Fort Peck Dam, is 18°C scheduled to occur at a time that mimics natural spring runoff and temperature increases, or beginning no sooner than May 15. The Omaha District sought to achieve these targets by releasing warm surface water from Fort Peck Lake through the spillway; however, due to low pool levels caused by multiyear drought, simulations of lake temperature and releases to the Missouri River through the spillway and a hypothetical high-level reservoir withdrawal were performed for a feasibility study. This section summarizes results of similar simulations performed for years 2004 – 2008.

The hypothetical high-level reservoir withdrawal that was simulated for this modeling report was a vertical extension of the existing outlet works wet well to an inlet elevation at 658.40 m (2160.10 ft). The purpose of the simulations was to demonstrate the capability of releasing warmer water to the Missouri River, and reach a target temperature of 18°C temperature at Frazer Rapids, MT. The following three sections discuss the water quality impacts of the high-level withdrawal and coldwater habitat characteristics and impacts.

6.1.1 Impact of High-Level Withdrawal on Reservoir Withdrawals Water Quality

Figure 6-1 plots powerhouse release temperatures from the high-level reservoir withdrawal for simulation years 2004 through 2008. Compared to temperatures released from the regular reservoir withdrawal (Figure 5-1), temperatures of water released through the high-level withdrawal increase more rapidly, reach a higher peak discharge temperature, and achieve the 18°C temperature target in the release water. Beginning on May 1, simulated temperatures in all five simulation years ranging from 5.0 to 7.0°C increase and peak near above 18°C and as much as 21°C from the last week in July to early September. Regular reservoir withdrawal temperatures peak between 14 and 17°C from the middle to the end of September. The 18°C temperature target was not first met until the first week of July in the 2007 and 2008 simulation years.

Figure 6-2 plots powerhouse release dissolved oxygen concentrations from the high-level reservoir withdrawal for simulation years 2004 through 2008. Dissolved oxygen trends followed a similar decreasing pattern as the regular reservoir withdrawal simulation plotted in Figure 5-2, with the exception that DO concentrations appear to level off beginning near the end of July rather than continue to decline until reservoir turnover in Figure 5-2. DO concentrations in 2004 – 2006 reach a minimum near 8.0 mg/L, and 2007 and 2008 concentrations reach 7.0 and 6.0 mg/L, respectively, while regular reservoir withdrawal simulations reach minimum DO concentrations in late September to early October. Lower DO concentrations in the regular withdrawal releases are expected because the regular withdrawal is deeper in the reservoir (638.6 m) compared to the high-level withdrawal (658.4 m), and lower DO concentrations consistently occur deeper in the reservoir because of sediment oxygen demand, organic matter degradation, and low aeration.

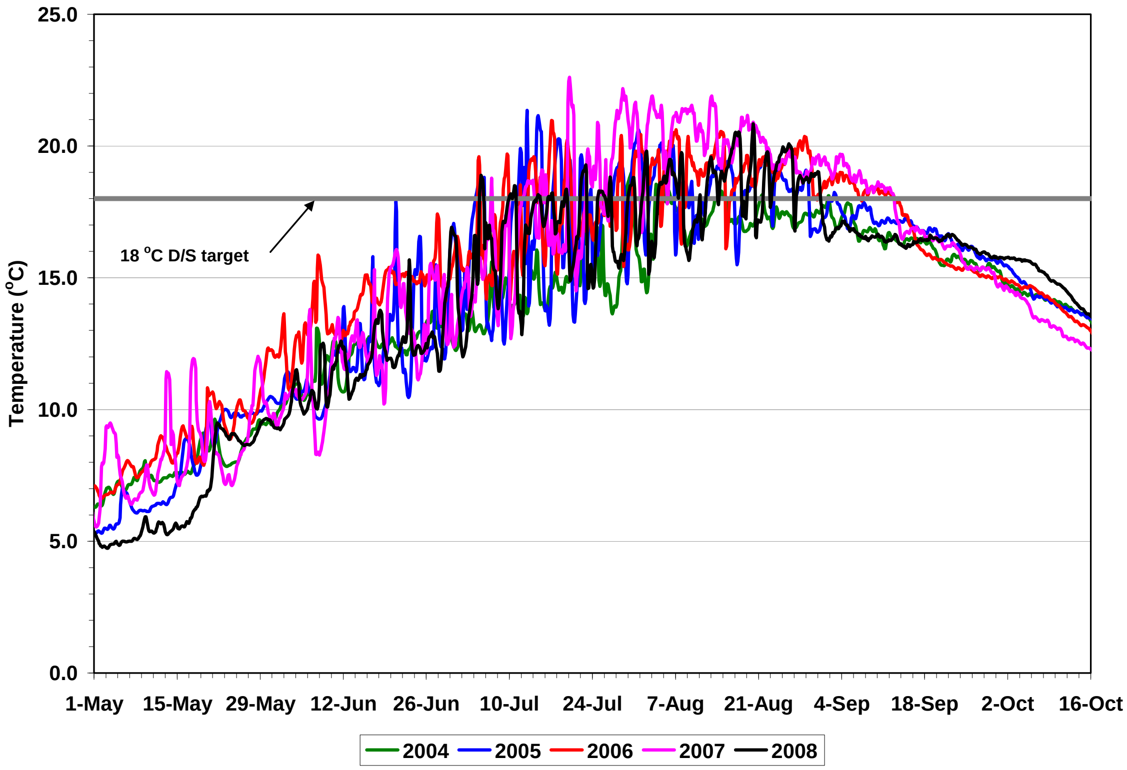

Figure 6-1. Simulated water temperatures (°C) in powerhouse release water for the hypothetical high-level reservoir withdrawal.

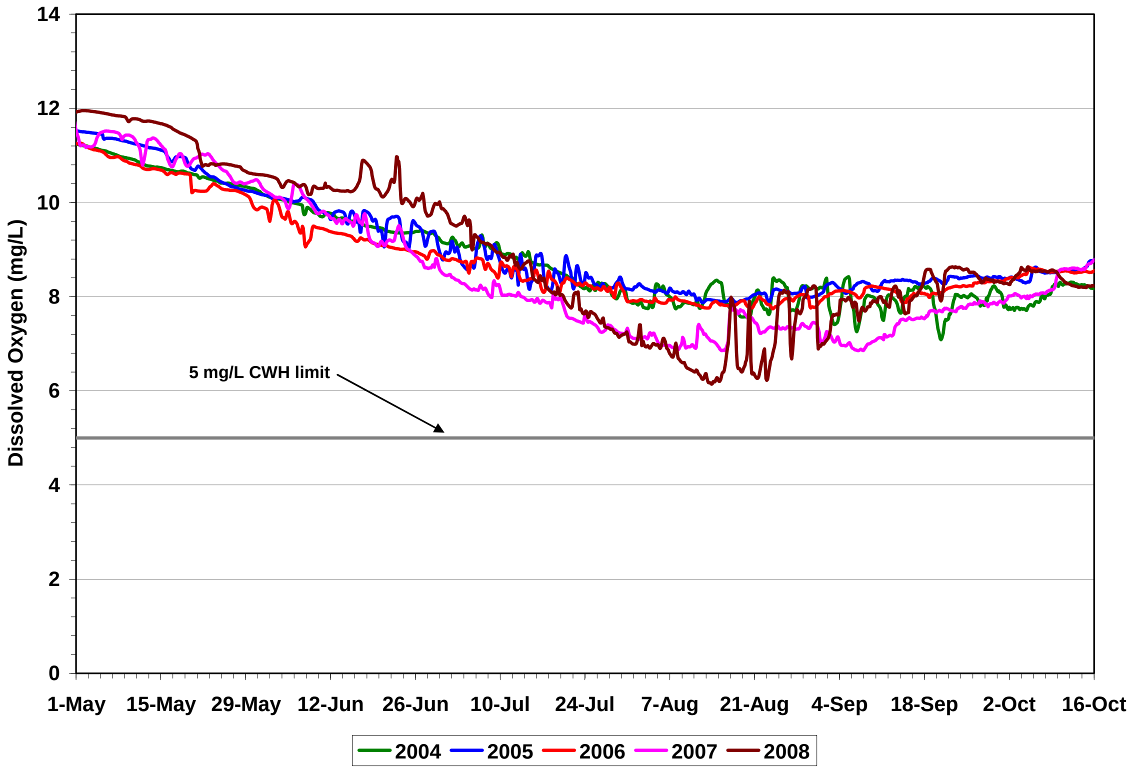

Figure 6-2. Simulated dissolved oxygen concentrations (mg/L) in powerhouse release water for the hypothetical high-level reservoir withdrawal.

6.1.2 IMPACT OF HIGH-LEVEL WITHDRAWAL ON COLDWATER HABITAT CRITERIA DEPTH

Optimal coldwater habitat criteria isotherm (15^{o}C) and DO (5 mg/L) isopleths elevations in the reservoir near Fort Peck Dam are plotted versus time for the regular withdrawal and high-level withdrawal simulations in Figures 6-3 through 6-7. Since the model is divided into 2-meter vertical layers and laterally averaged, simulation precision is limited, which also limits the simulated differences between without and with intake scenarios elevations. In all simulations the high-level withdrawal limited the depth of the declining 15^{o}C isotherm; however, it had limited impact on the 5 mg/L DO isopleths. The limitation of the declining depth caused by the high-level withdrawal is a function of the preservation of colder water in the lower reservoir depths and release of warmer water from around 658.40 m (2160.10 ft).

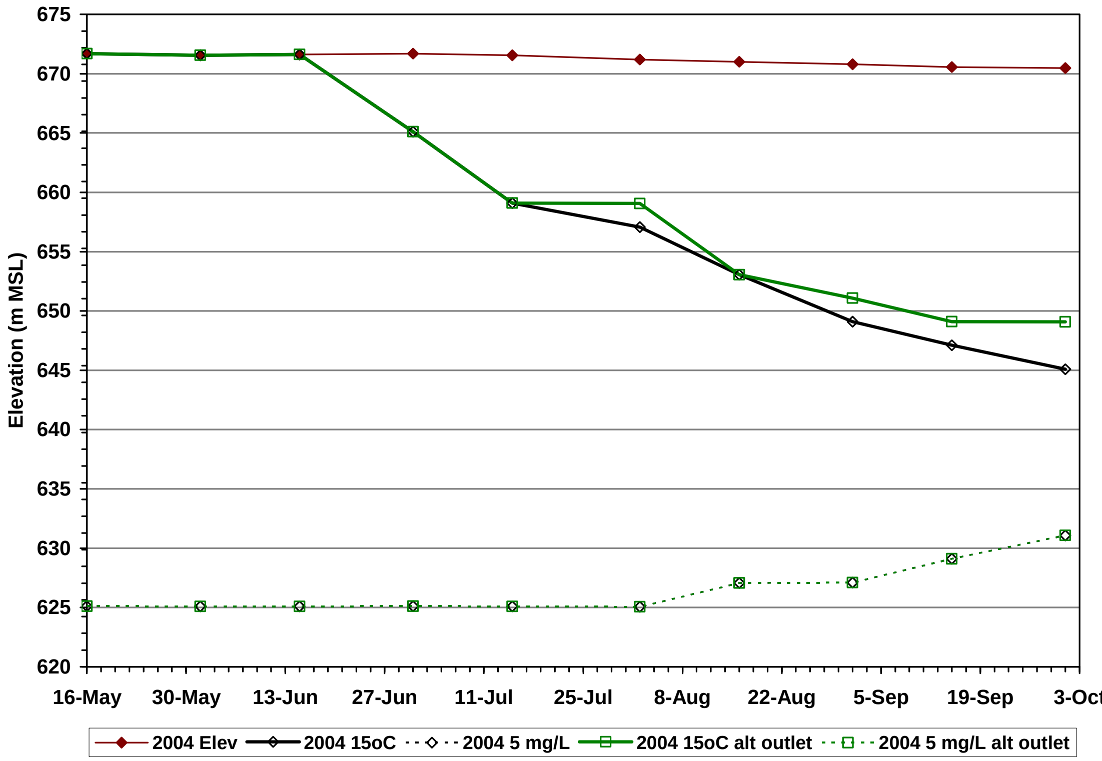

Figure 6-3. Elevation of simulated lake surface, 15^{o}C temperature, and 5 mg/L dissolved oxygen isopleth during 2004 at station L1, with the normal (black) and hypothetical high-level (green) withdrawals.

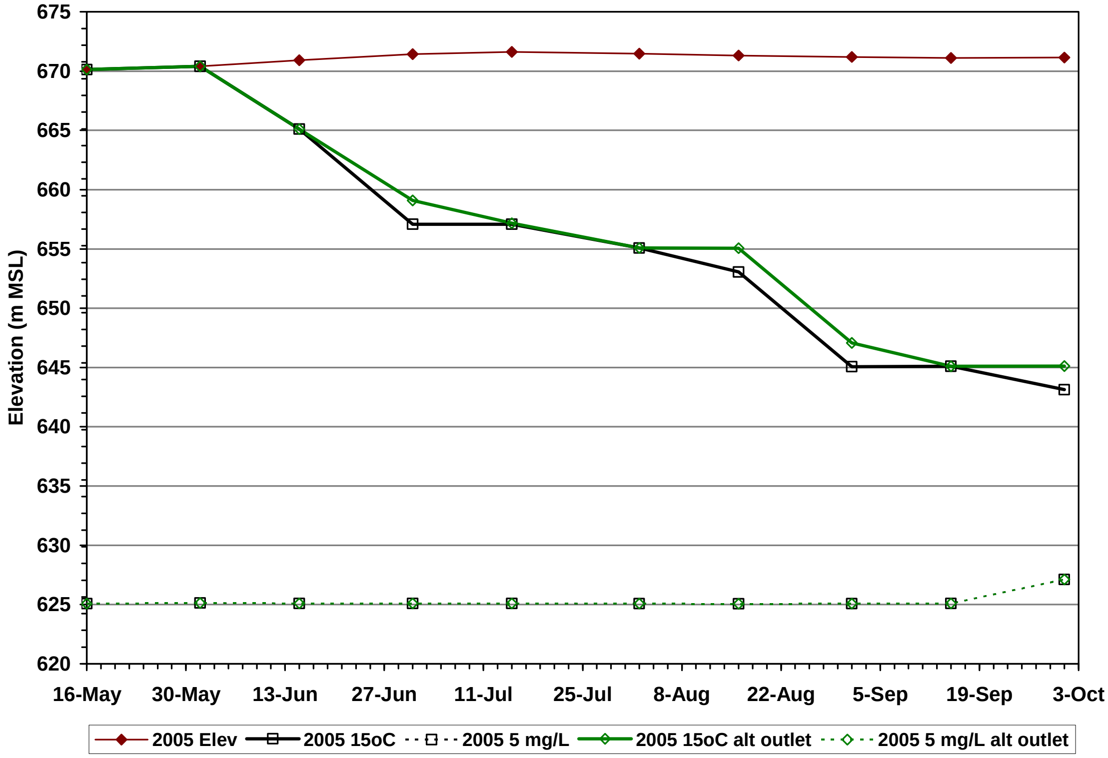

Figure 6-4. Elevation of simulated lake surface, 15°C temperature, and 5 mg/L dissolved oxygen isopleth during 2005 at station L1, with the normal (black) and hypothetical high-level (green) withdrawals.

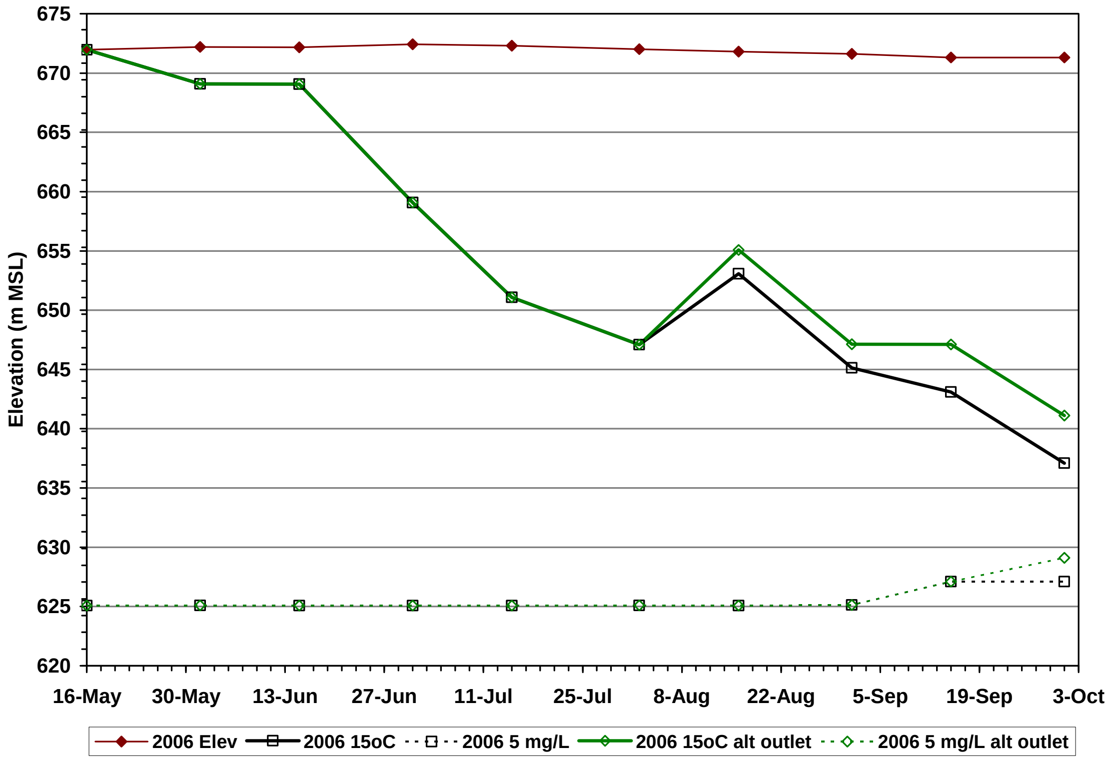

Figure 6-5. Elevation of simulated lake surface, 15°C temperature, and 5 mg/L dissolved oxygen isopleth during 2006 at station L1, with the normal (black) and hypothetical high-level (green) withdrawals.

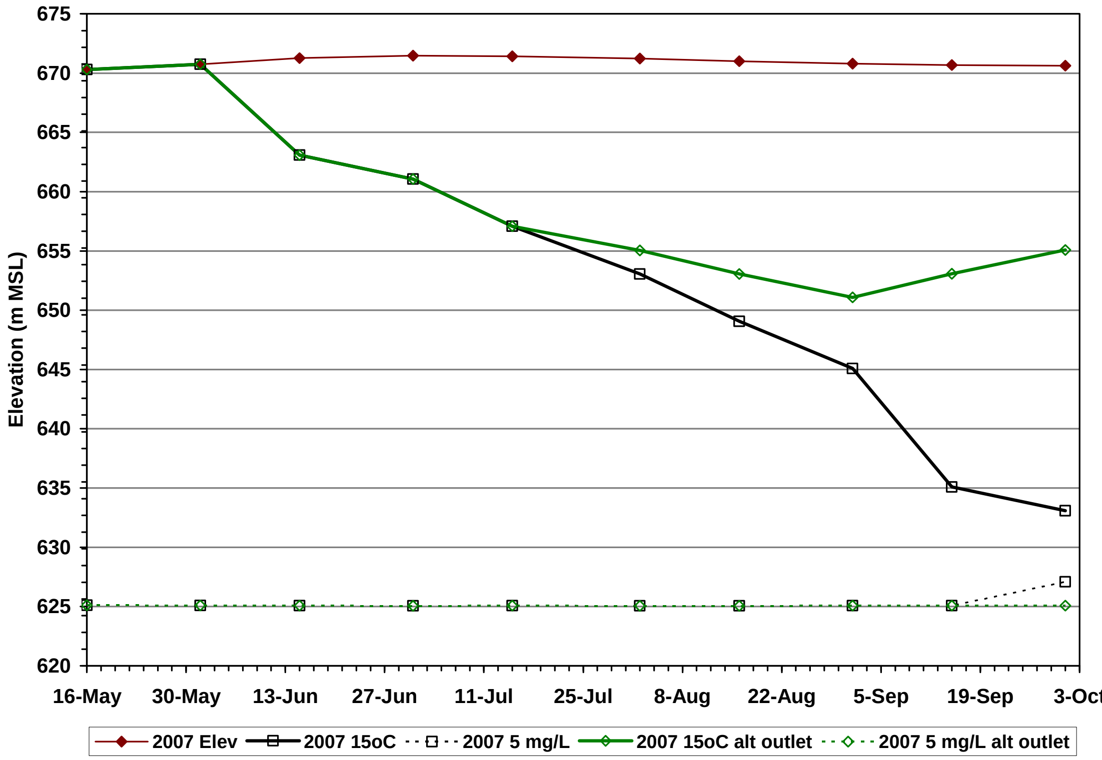

Figure 6-6. Elevation of simulated lake surface, 15°C temperature, and 5 mg/L dissolved oxygen isopleth during 2007 at station L1, with the normal (black) and hypothetical high-level (green) withdrawals.

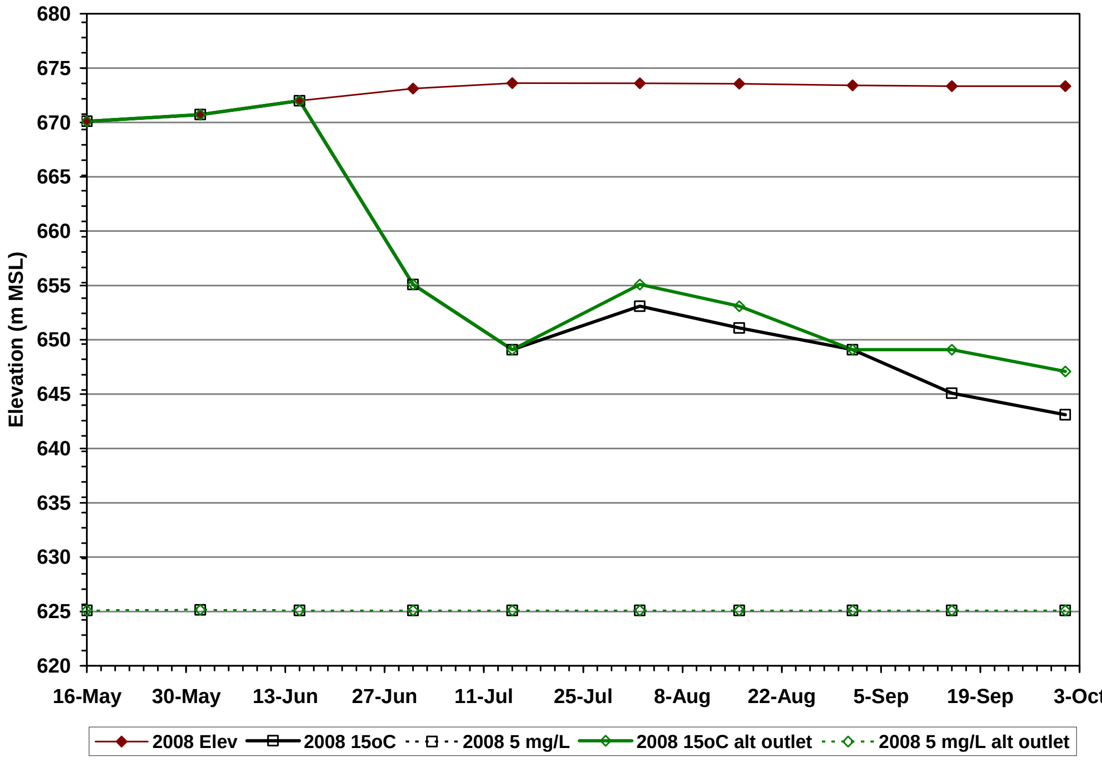

Figure 6-7. Elevation of simulated lake surface, 15°C temperature, and 5 mg/L dissolved oxygen isopleth during 2008 at station L1, with the normal (black) and hypothetical high-level (green) withdrawals.

6.1.3 IMPACT OF HIGH-LEVEL WITHDRAWAL ON COLDWATER HABITAT VOLUME

The impact of the simulated high-level withdrawal on CWH volume is quantified on water quality sampling dates and summarized in Table 6-1. Time series plots of simulated optimal and total CWH are also plotted in Figures 6-8 through 6-12. Optimal CWH volume is expressed in MAF for the normal and high-level withdrawal simulations, and the difference between the two are provided. In general the volume of CWH when the high-level withdrawal is simulated was greater than the volume of CWH when the normal withdrawal was simulated.

CWH savings induced by the high-level withdrawal were generally greatest from mid-August to early September when thermal stratification was at its greatest prior to the beginning of fall cooling and lake turnover. This coincides with the time period when CWH is stressed the most and is driven to the deepest regions of the reservoir. The Fort Peck wet well intake crest elevation resides at 638.6 m (2095 ft) and the deepest part of the reservoir extends downward below 620 m (2034 ft). The regular intake level generally is below the reservoir thermocline until late in the summer, so it generally withdraws "coldwater habitat criteria" water. The hypothetical high-level withdrawal intercepts the thermocline throughout much of the summer so it withdraws warmer, "non-criteria" water. Coldwater savings can be attributed to the withdrawal elevation characteristic.

Minimum CWH for both cases are provided in the Minimum CWH row of each year. At minimum CWH, savings induced by the high-level withdrawals was greatest in 2007 at 1.21 MAF with much less CWH savings in all other years. Simulation year 2007 was the outlier compared to other simulation years with regard to coldwater habitat savings.

Table 6-1. Comparison of simulated optimal CWH (T < 15°C, DO > 5 mg/L) volume between simulations with and without a hypothetical high-level reservoir withdrawal.

Date	Simulated Optimal CWH, Million acre-feet (MAF)		
	Normal Withdrawal	High-Level Withdrawal	Difference
24 June 2004	7.498	7.589	0.092
19 July 2004	3.990	4.088	0.098
24 August 2004	1.655	1.969	0.314
8 September 2004	1.284	1.694	0.411
20 September 2004	1.037	1.487	0.450
Minimum CWH	0.936	1.308	0.372
22 June 2005	5.048	5.036	-0.011
20 July 2005	3.294	3.312	0.019
24 August 2005	2.050	2.326	0.276
19 September 2005	0.947	1.275	0.328
Minimum CWH	0.880	1.186	0.305
20 June 2006	4.496	4.650	0.153
25 July 2006	2.393	2.609	0.216
29 August 2006	1.395	1.768	0.373
13 September 2006	0.853	1.157	0.303
3 October 2006	1.776	5.890	4.114
Minimum CWH	0.594	0.813	0.218
22 May 2007	7.928	7.951	0.023
27 June 2007	4.384	4.380	-0.005
24 July 2007	2.677	2.946	0.269
21 August 2007	1.596	2.295	0.700
11 September 2007	0.661	1.996	1.334
25 September 2007	1.084	2.325	1.241
Minimum CWH	0.621	1.827	1.206
7 May 2008	8.471	8.471	0.000
4 June 2008	8.118	8.135	0.017
10 July 2008	3.922	4.064	0.413
7 August 2008	2.537	2.715	0.178
9 September 2008	1.078	1.441	0.363
Minimum	0.755	1.216	0.461

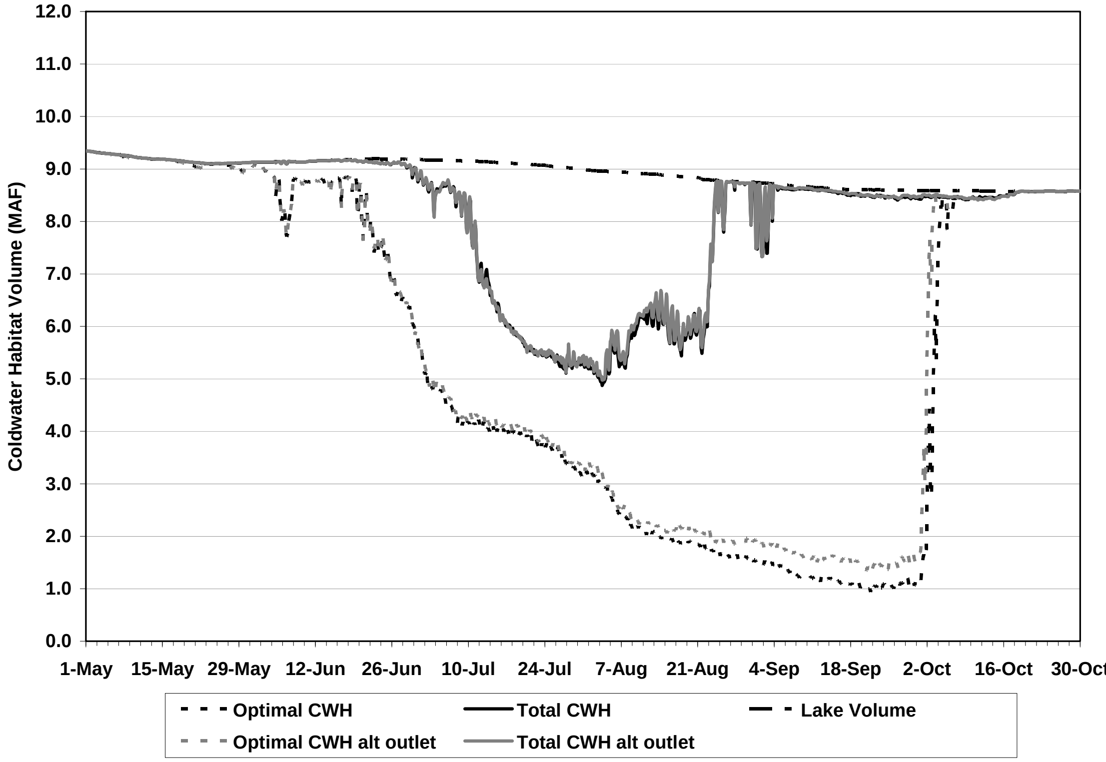

Figure 6-8. Simulated volume of optimal and total CWH in Fort Peck Lake during 2004 simulated with the normal outlet (black) and a hypothetical high-level outlet (gray).

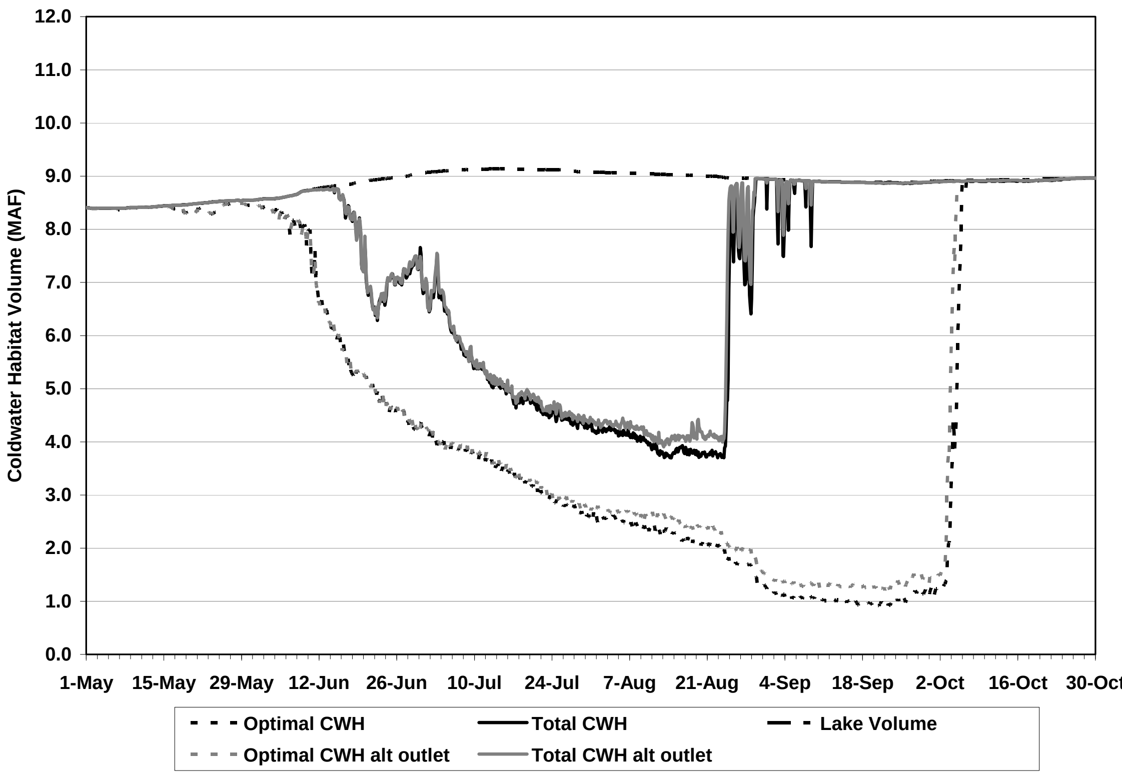

Figure 6-9. Simulated volume of optimal and total CWH in Fort Peck Lake during 2005 simulated with the normal outlet (black) and a hypothetical high-level outlet (gray).

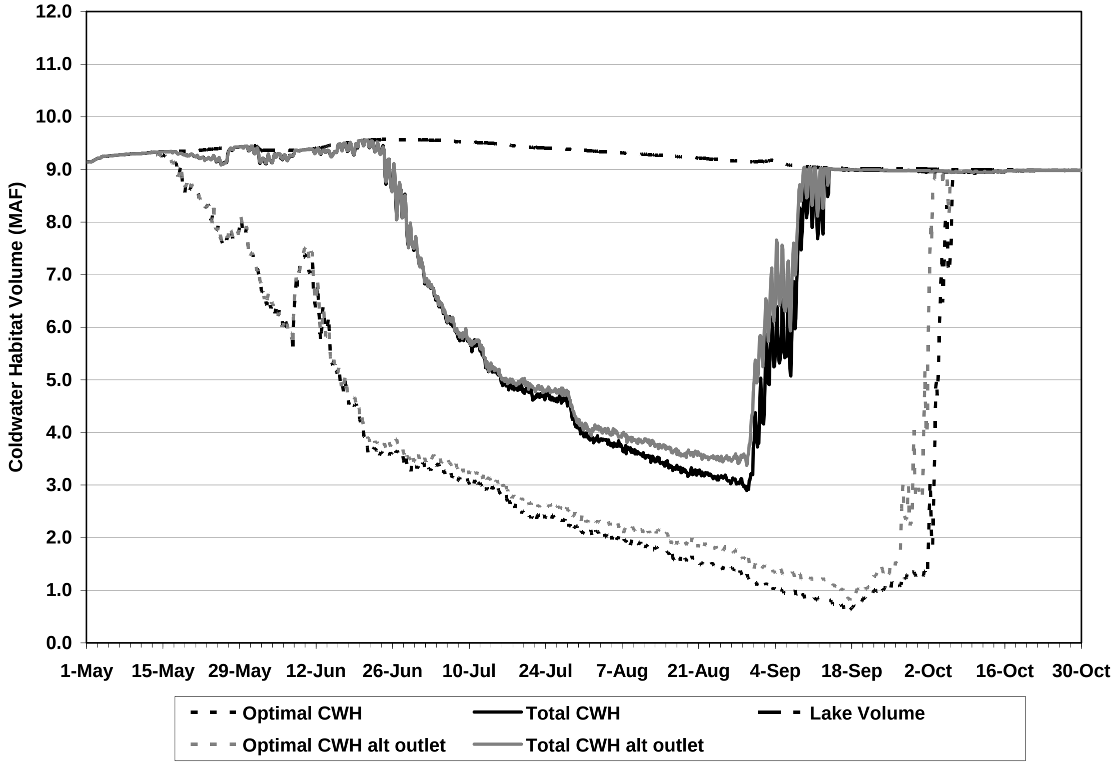

Figure 6-10. Simulated volume of optimal and total CWH in Fort Peck Lake during 2006 simulated with the normal outlet (black) and a hypothetical high-level outlet (gray).

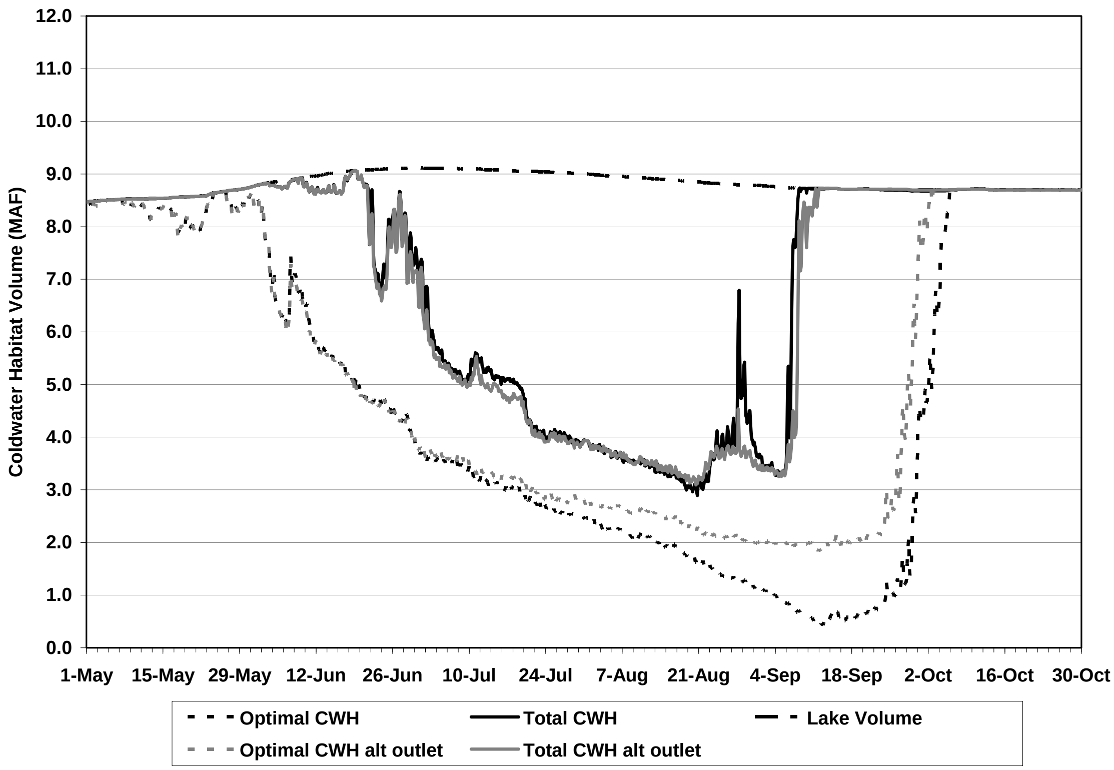

Figure 6-11. Simulated volume of optimal and total CWH in Fort Peck Lake during 2007 simulated with the normal outlet (black) and a hypothetical high-level outlet (gray).

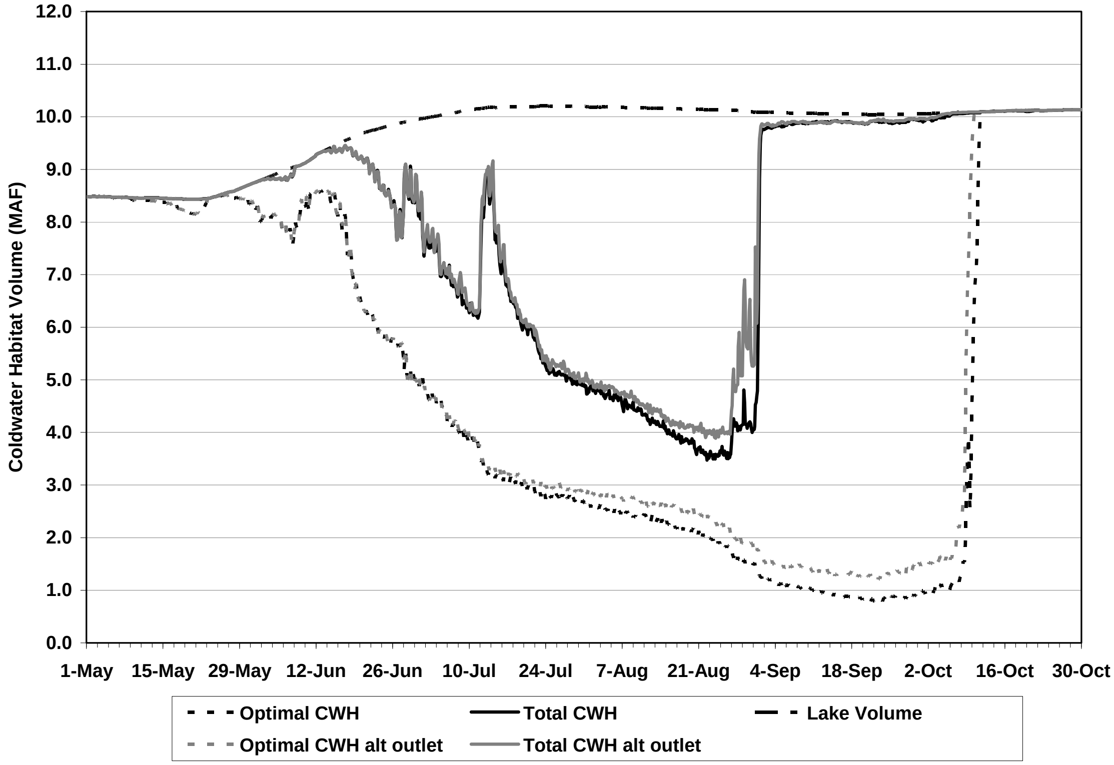

Figure 6-12. Simulated volume of optimal and total CWH in Fort Peck Lake during 2008 simulated with the normal outlet (black) and a hypothetical high-level outlet (gray).

7 FUTURE MODEL APPLICATIONS

7.1 IMPACT OF RESERVOIR STORAGE/POOL ELEVATION ON RESERVOIR WATER QUALITY

Water quality data since 2004 and calibrated water quality and temperature simulations portray Fort Peck Lake in a low pool drought affected state. From 2004 to 2008, pool elevations ranged from 669.4 m (2196.1 ft) to 637.7 m (2210.2 ft). The base of the flood control pool elevation is 648.6 m (2246 ft) and the average annual pool elevation from 1967 to 1997 was 560.3 m (2234.9 ft) (MRR RCC, 1999).

In order to accurately assess the impacts of low storage and pool elevations, water quality data through water quality surveys and reservoir simulations is needed from normal and high pool states. Additional simulations at median, low pool (lower decile) and high pool (upper decile) states should be performed to understand the sensitivity of water quality and CWH to pool elevations. The model could also be used to identify pool elevation or storage thresholds where CWH depletion becomes an issue.

7.2 IMPACT OF RESERVOIR STORAGE/POOL ELEVATION ON WARM WATER RELEASES TO THE MISSOURI RIVER

Since water quality data and calibrated water quality and temperature simulations portray Fort Peck Lake in a low pool drought affected state, simulations of warm water releases through a hypothetical high-level withdrawal and the spillway could be performed for a model calibrated to normal and high pool states monitored in the field.

7.3 RESERVOIR REGULATION IMPACTS TO WATER QUALITY

A long range goal of reservoir water quality modeling is to evaluate water quality impacts in the Mainstem reservoirs as a result of system-wide operating decisions. For example a system of reservoir and river models linked in series could demonstrate the water quality impacts of storage unbalancing that regularly is performed in the upper three reservoirs, or the impact of water quality measures on the entire system. Considering the growing demand for recreational, wildlife habitat, and water supply uses a system of models would serve as a decision support system for future water allocations and operations.

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9 SUPPLEMENT FIGURES

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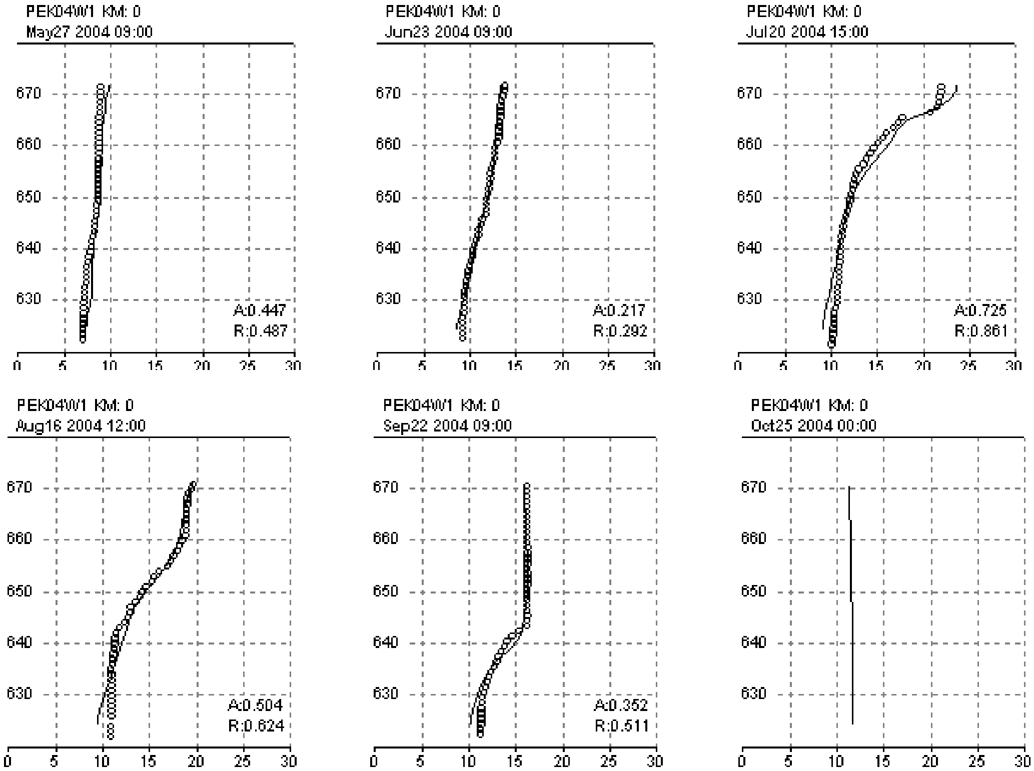


Figure 9-1. 2004 temperature calibration at L1.

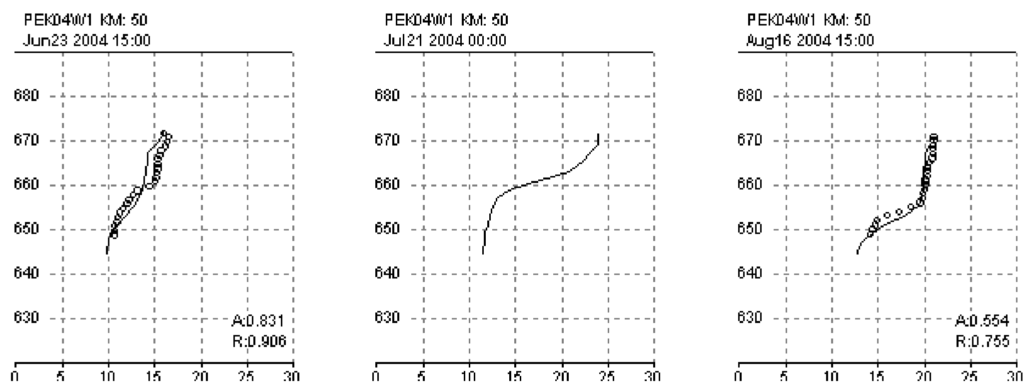


Figure 9-2. 2004 temperature calibration at L4.

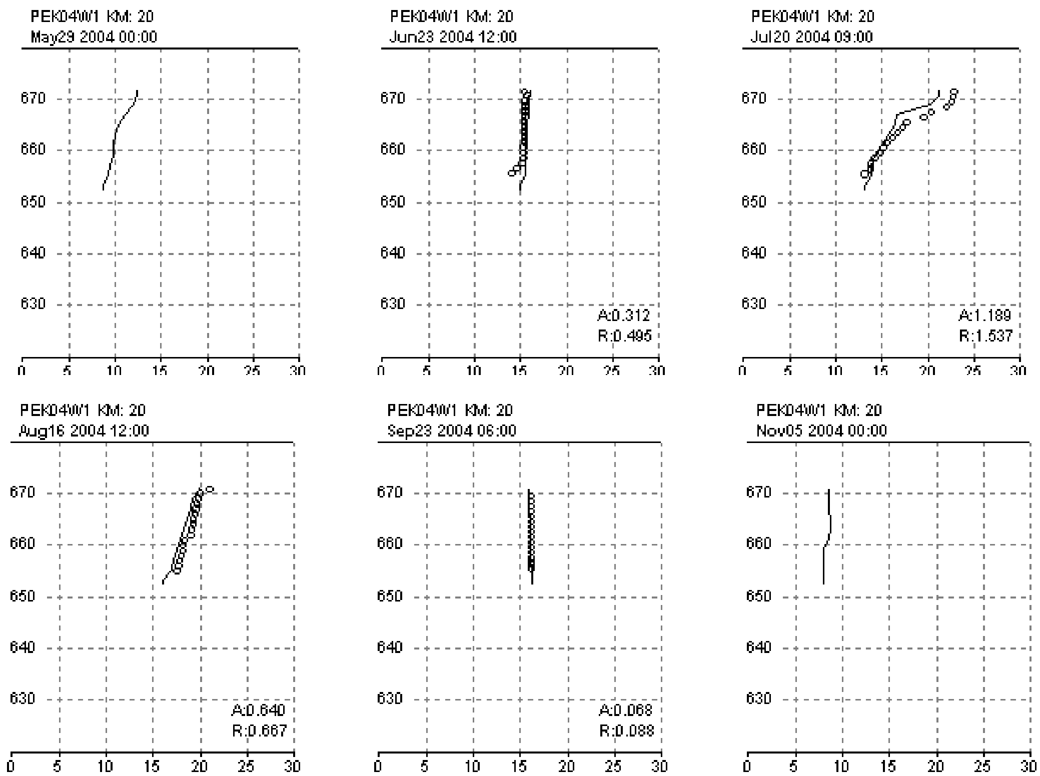


Figure 9-3. 2004 temperature calibration at L6.

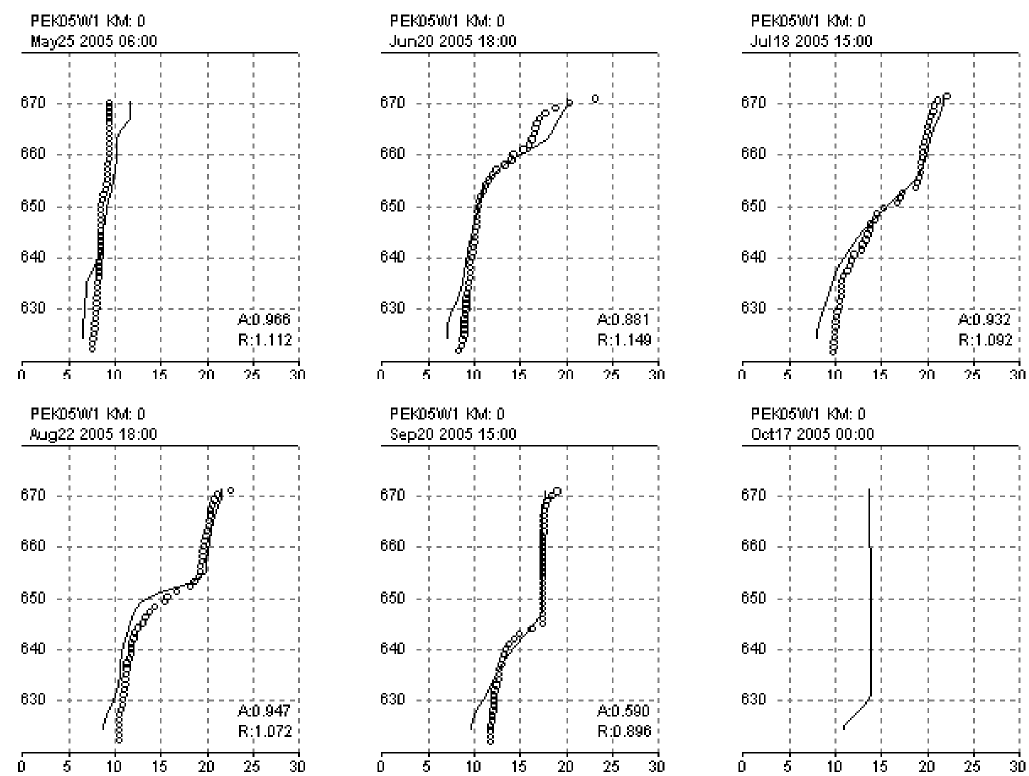


Figure 9-4. 2005 temperature calibration at L1.

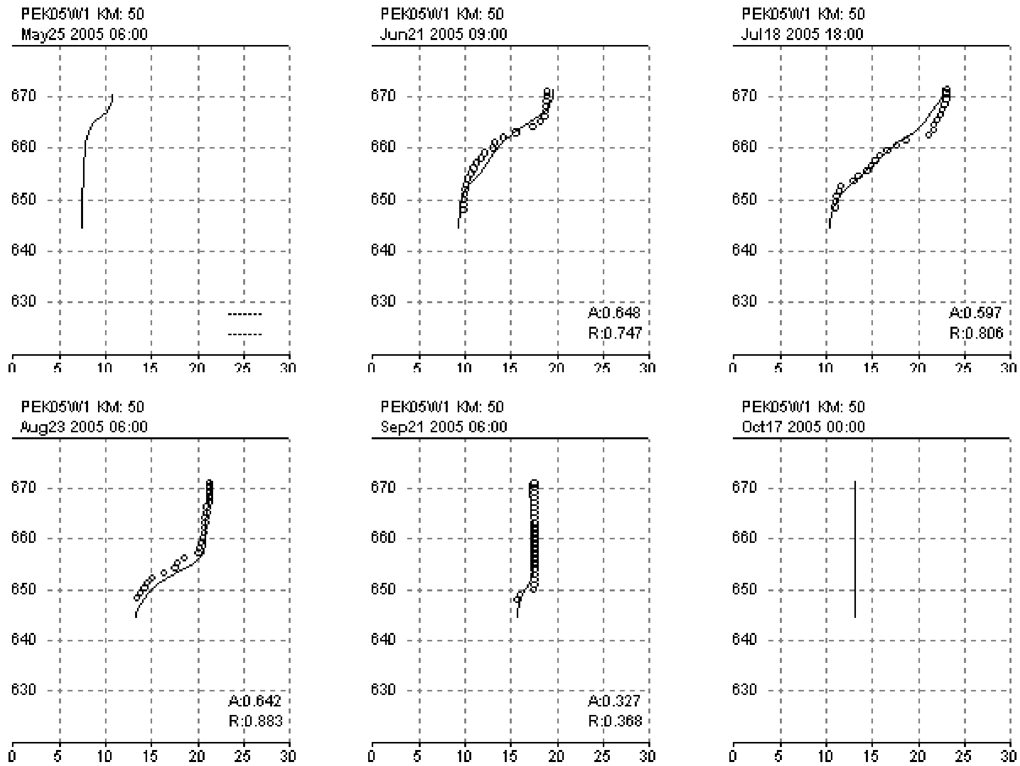


Figure 9-5. 2005 temperature calibration at L4.

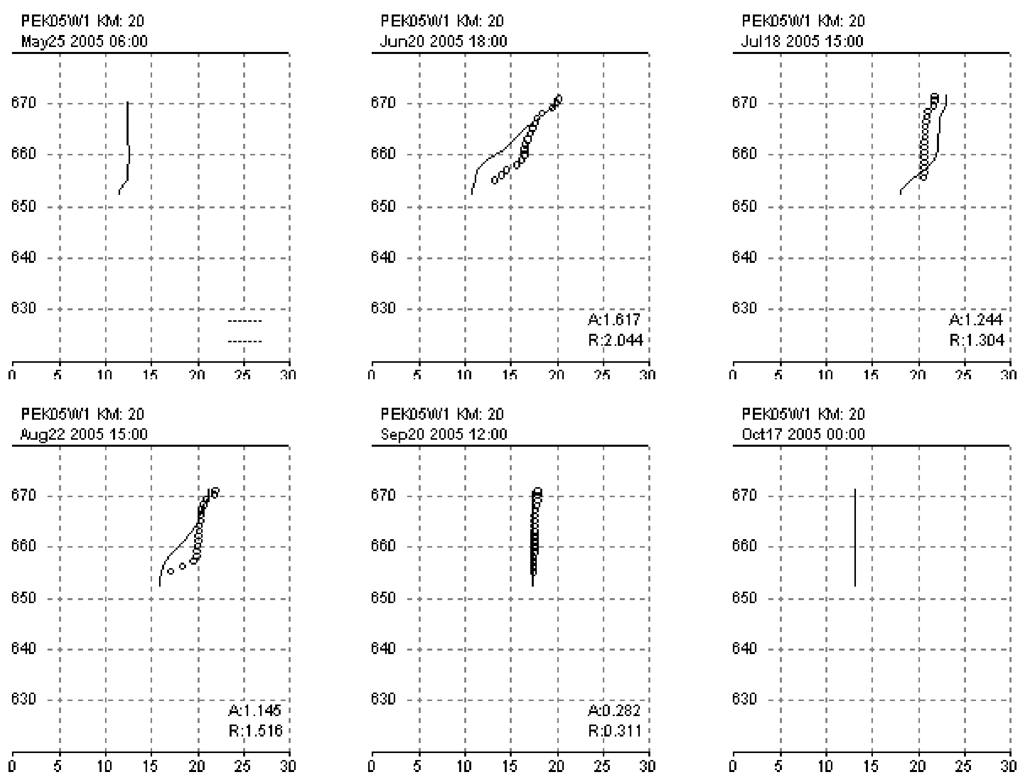


Figure 9-6. 2005 temperature calibration at L6.

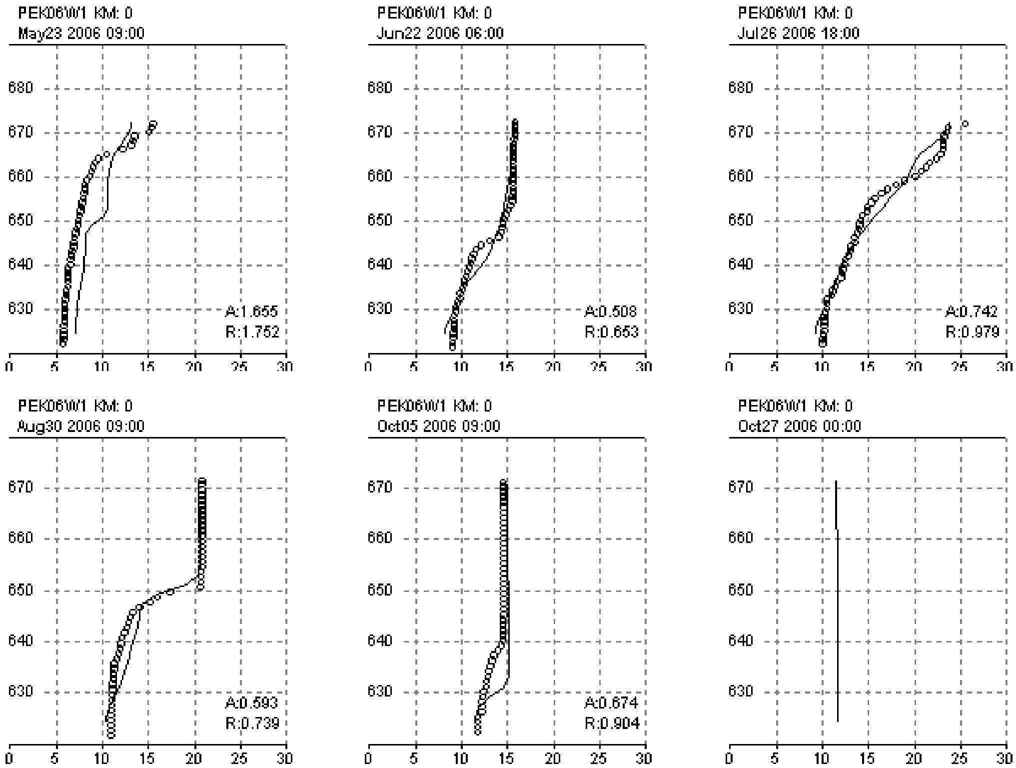


Figure 9-7. 2006 temperature calibration at L1.

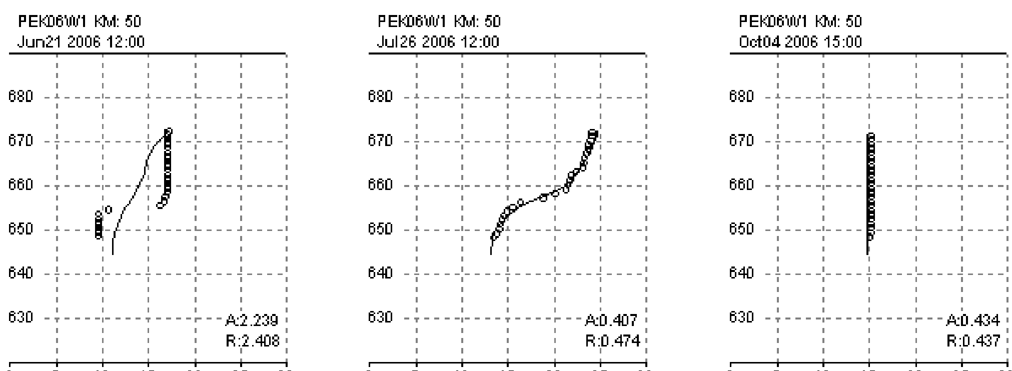


Figure 9-8. 2006 temperature calibration at L4.

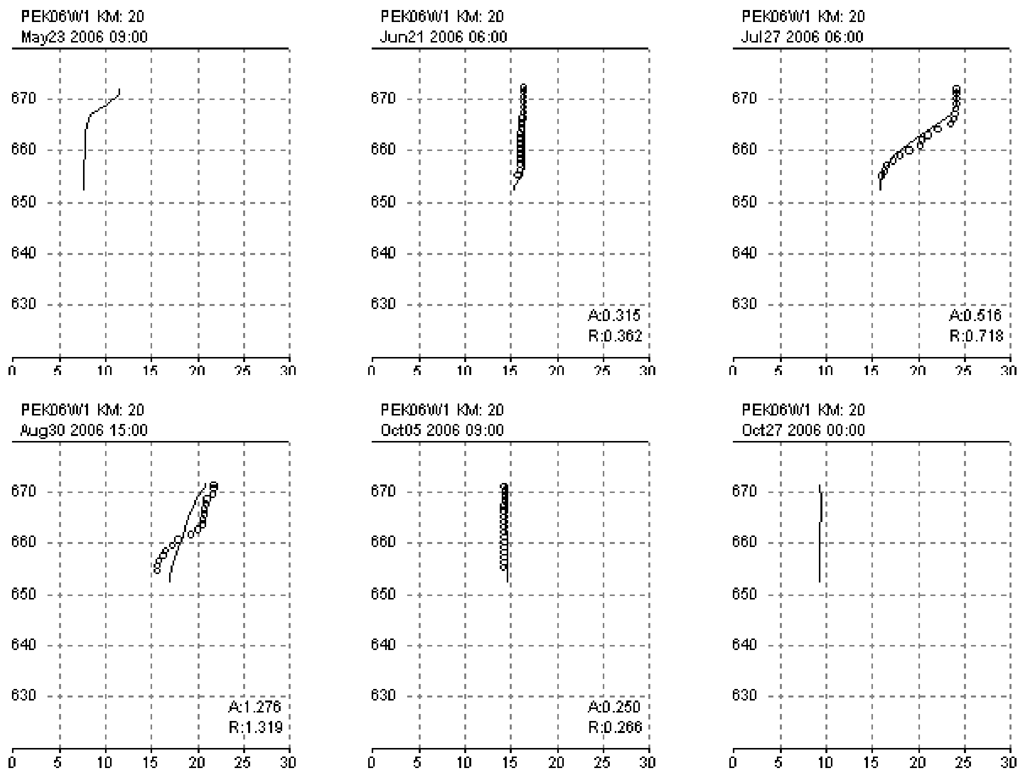


Figure 9-9. 2006 temperature calibration at L6.

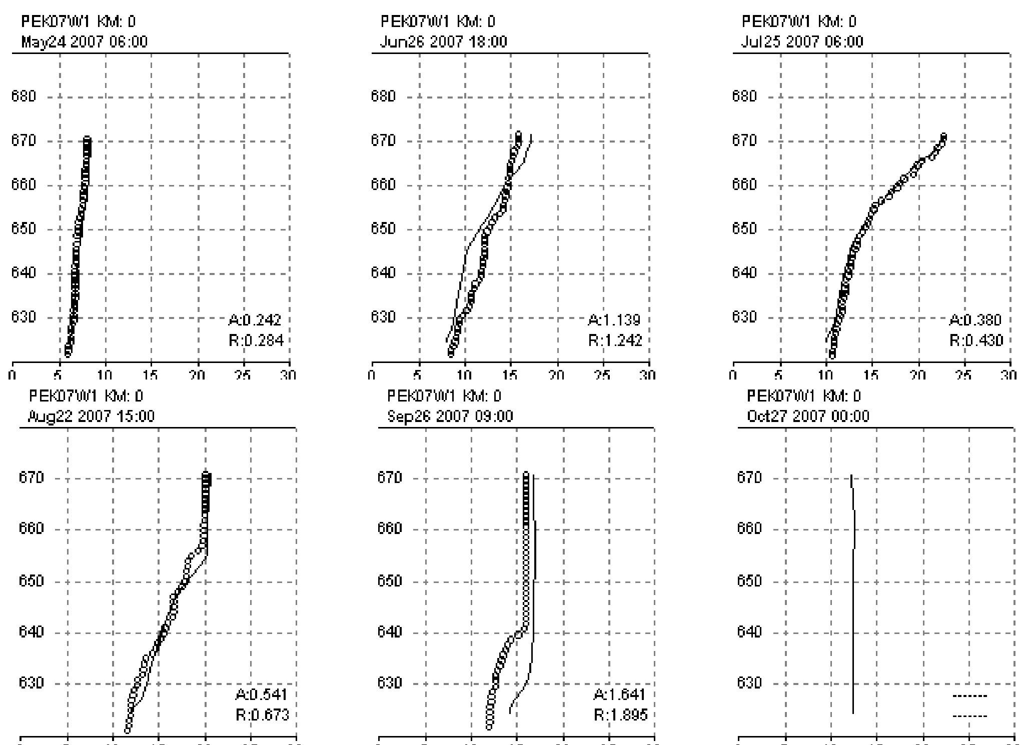


Figure 9-10. 2007 temperature calibration at L1.

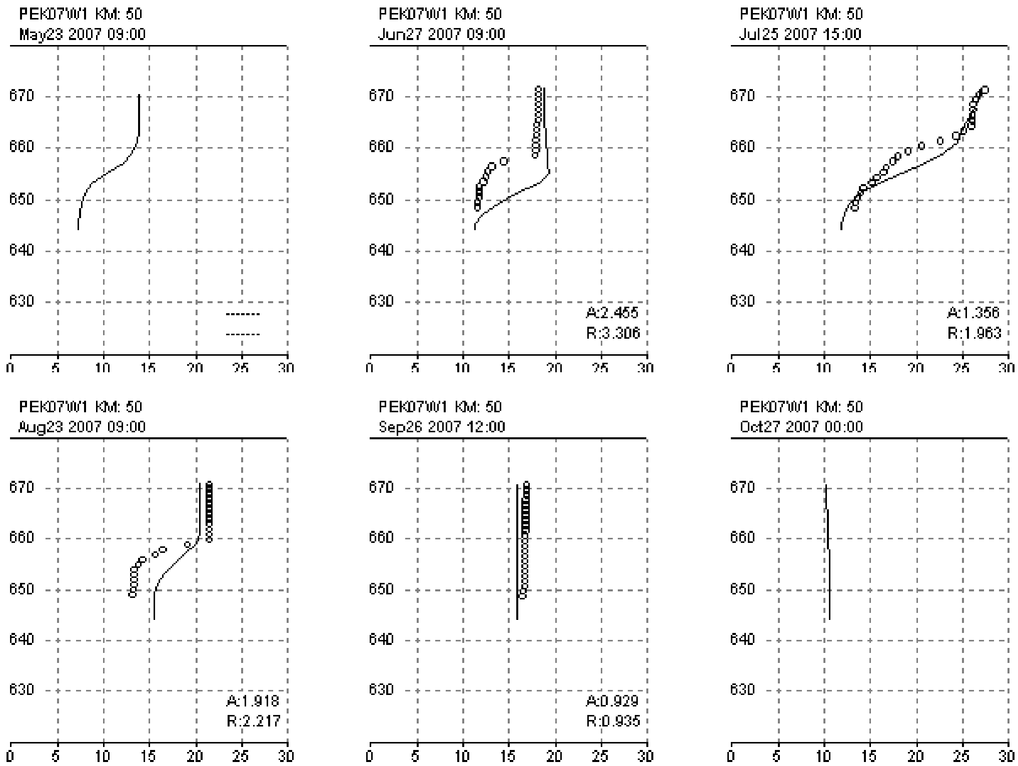


Figure 9-11. 2007 temperature calibration at L4.

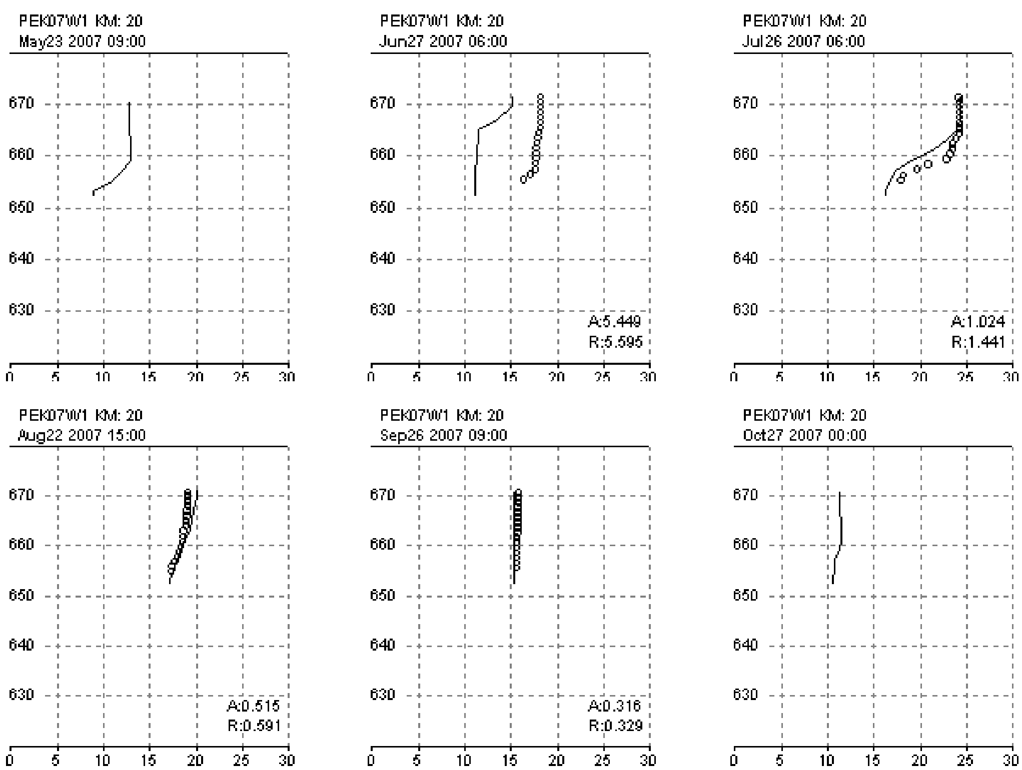


Figure 9-12. 2007 temperature calibration at L6.

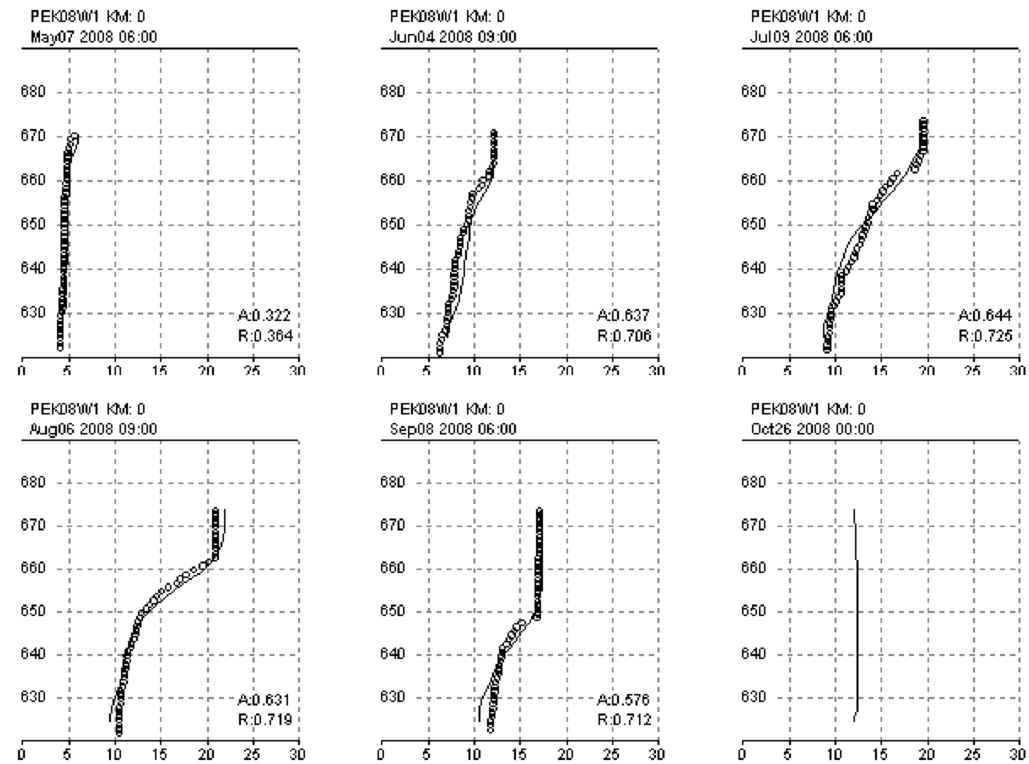


Figure 9-13. 2008 temperature calibration at L1.

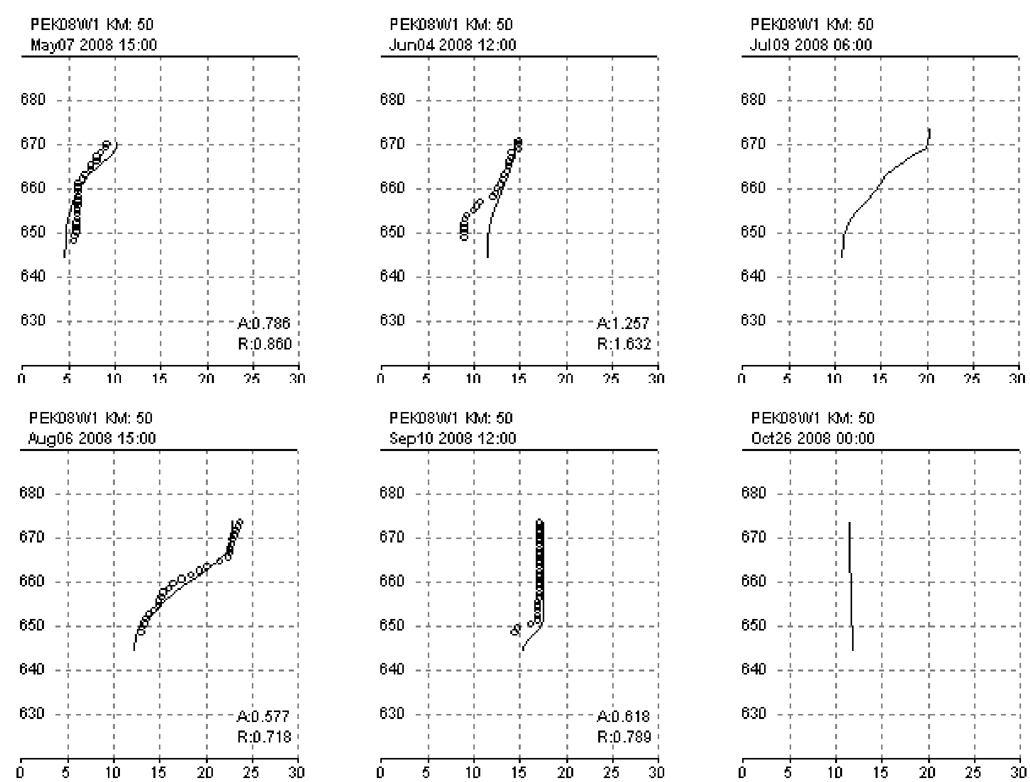


Figure 9-14. 2008 temperature calibration at L4.

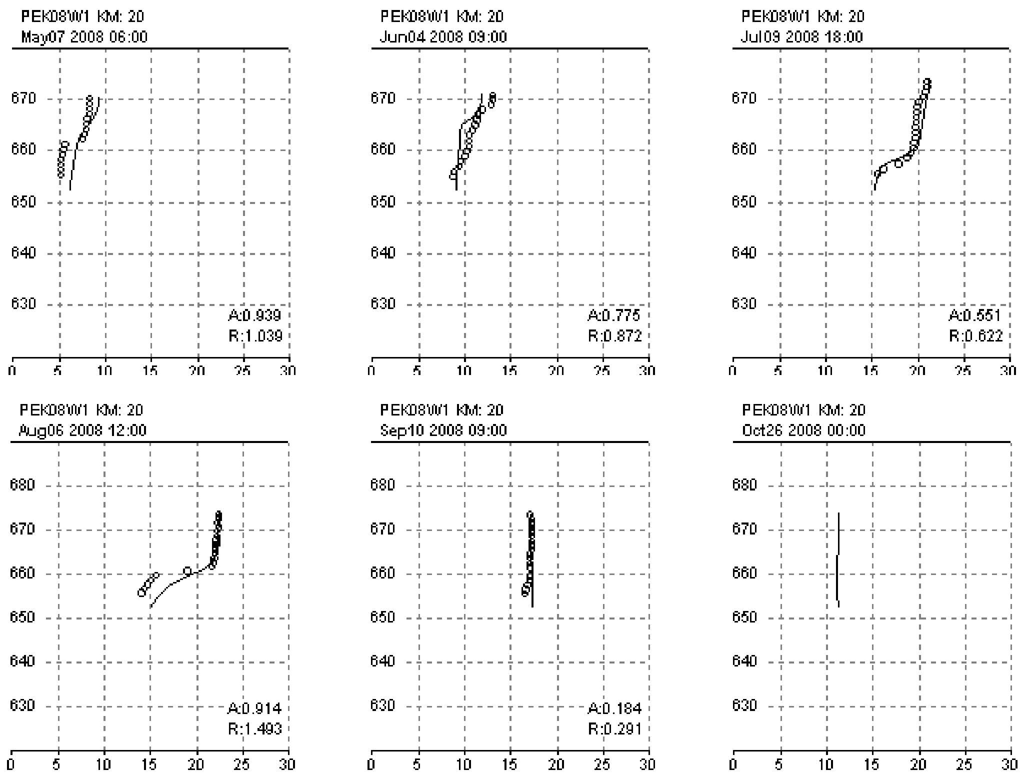


Figure 9-15. 2008 temperature calibration at L6.

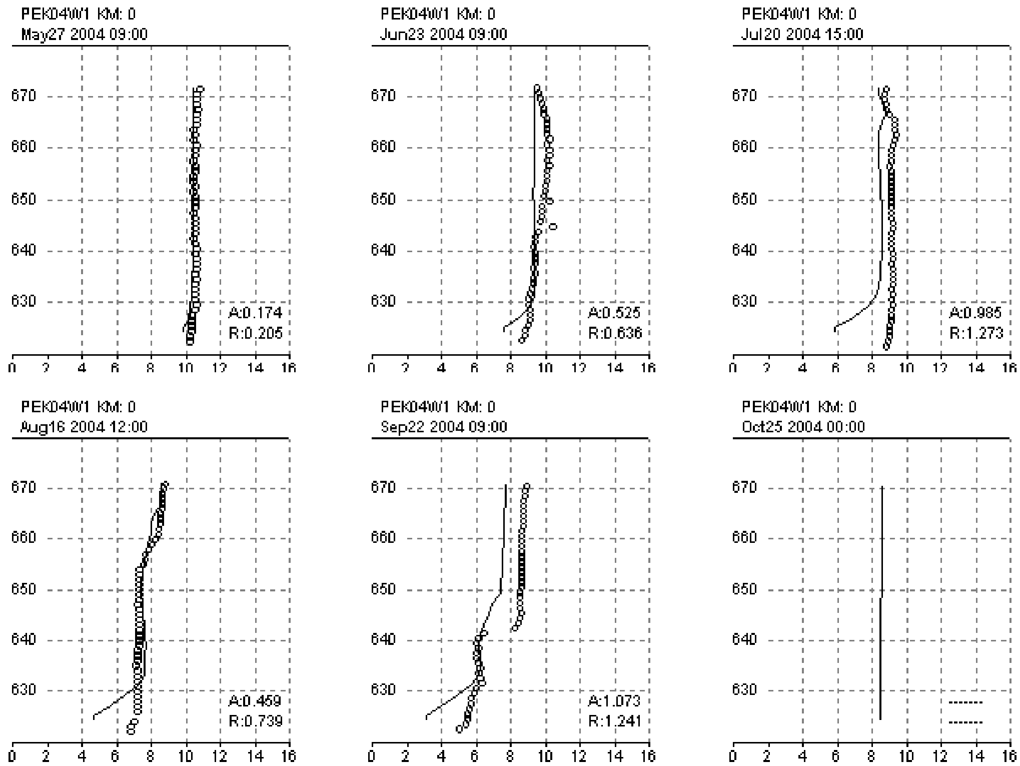


Figure 9-16. 2004 dissolved oxygen calibration at L1.

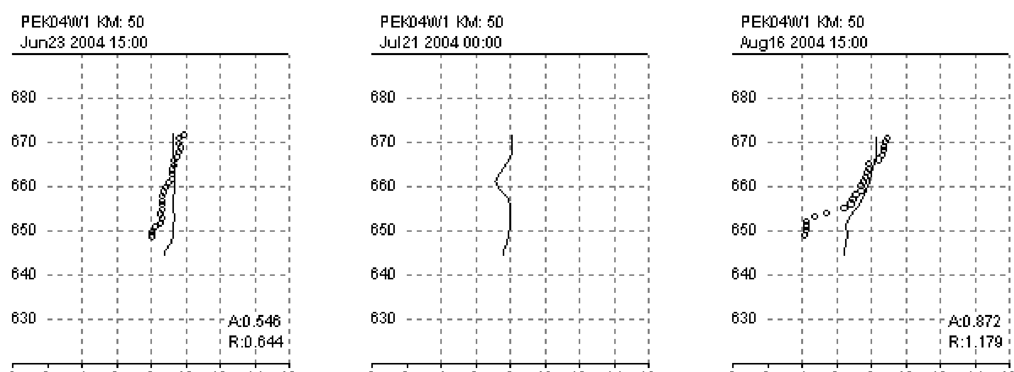


Figure 9-17. 2004 dissolved oxygen calibration at L4.

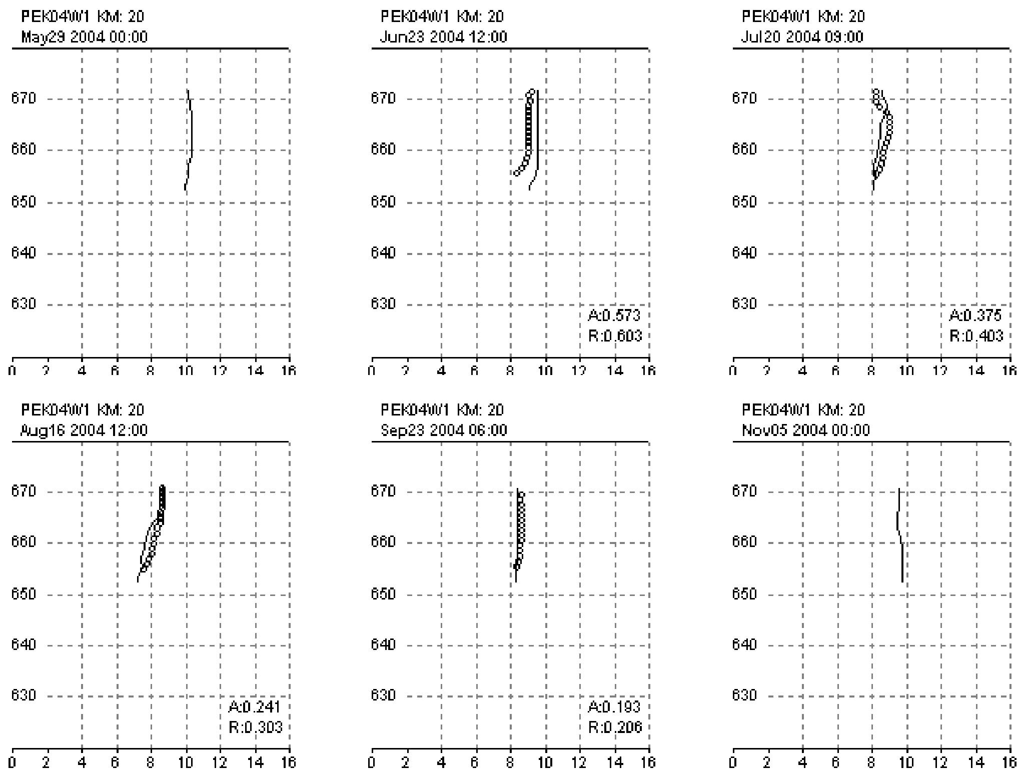


Figure 9-18. 2004 dissolved oxygen calibration at L6.

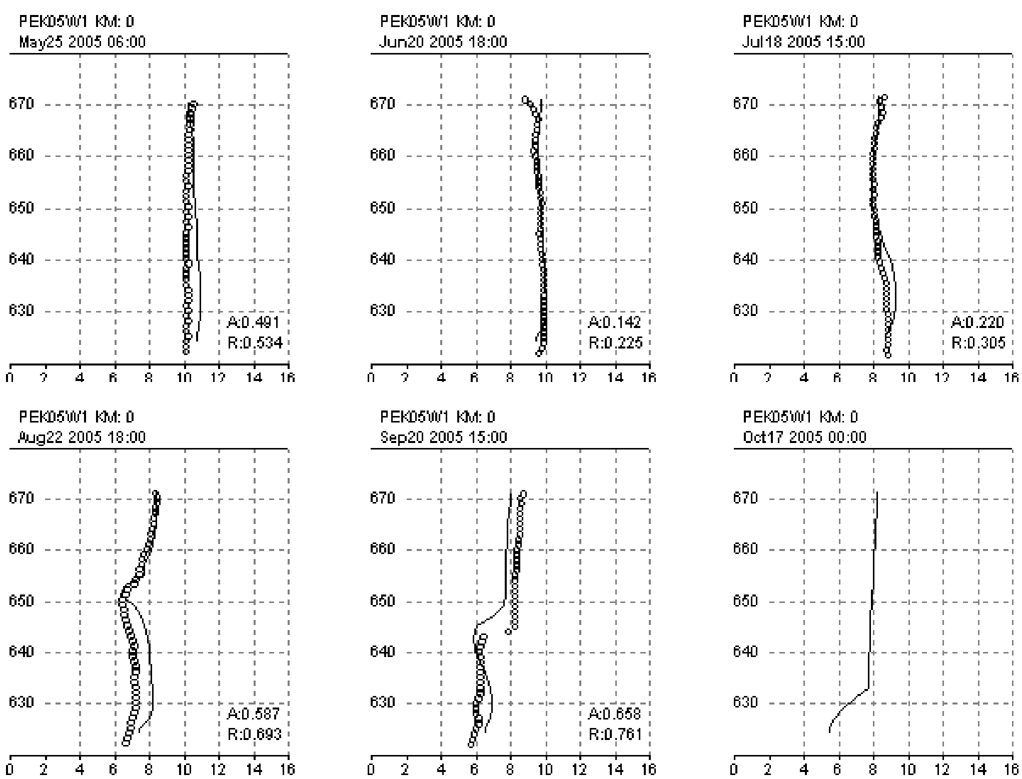


Figure 9-19. 2005 dissolved oxygen calibration at L1.

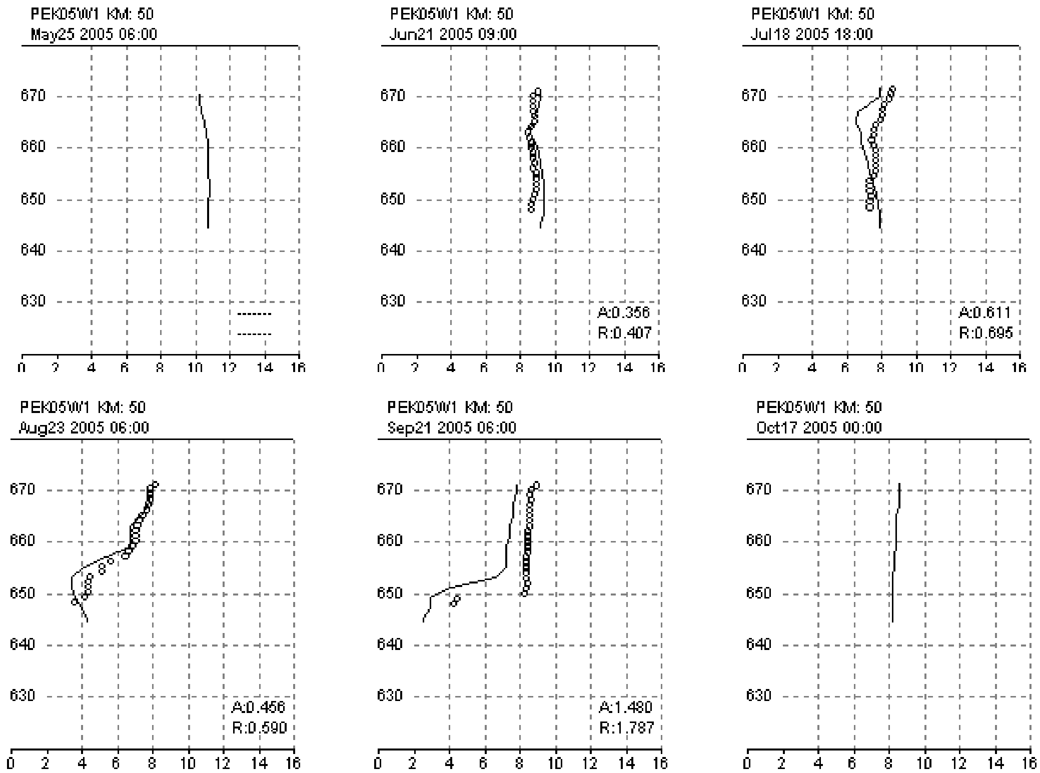


Figure 9-20. 2005 dissolved oxygen calibration at L4.

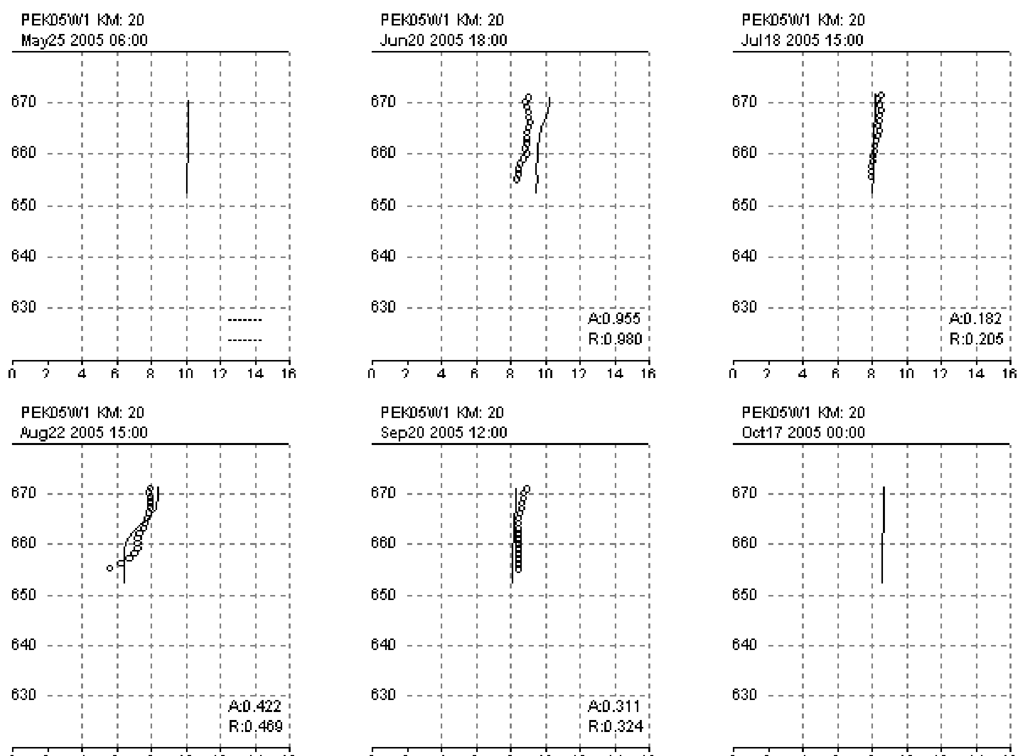


Figure 9-21. 2005 dissolved oxygen calibration at L6.

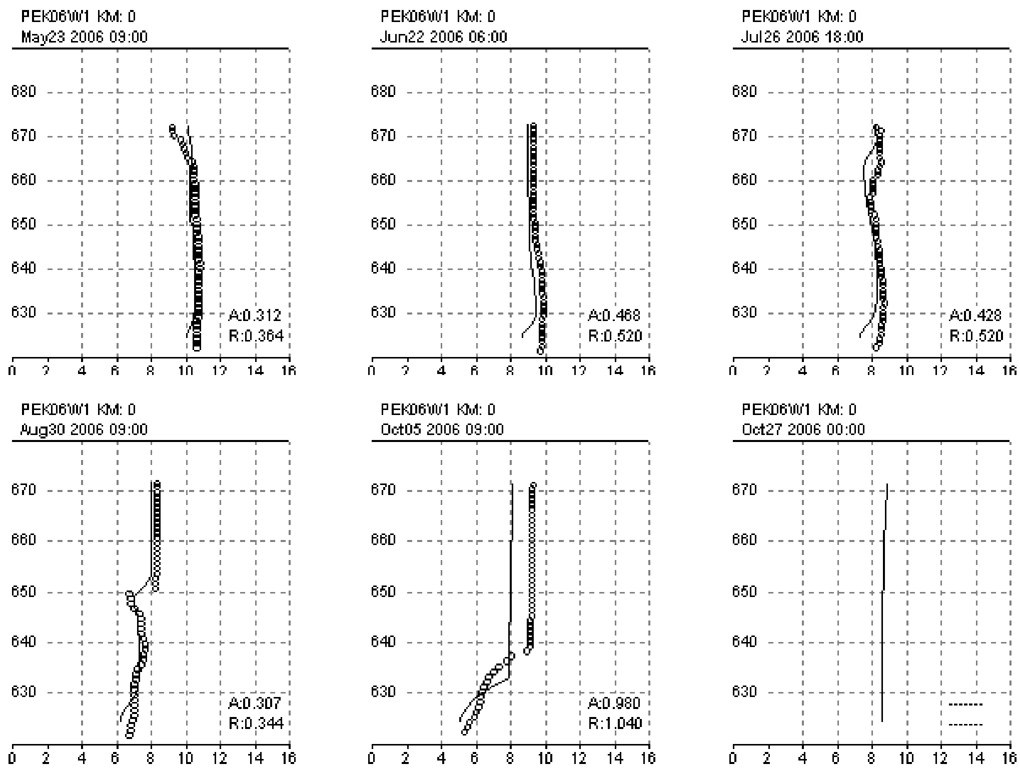


Figure 9-22. 2006 dissolved oxygen calibration at L1.

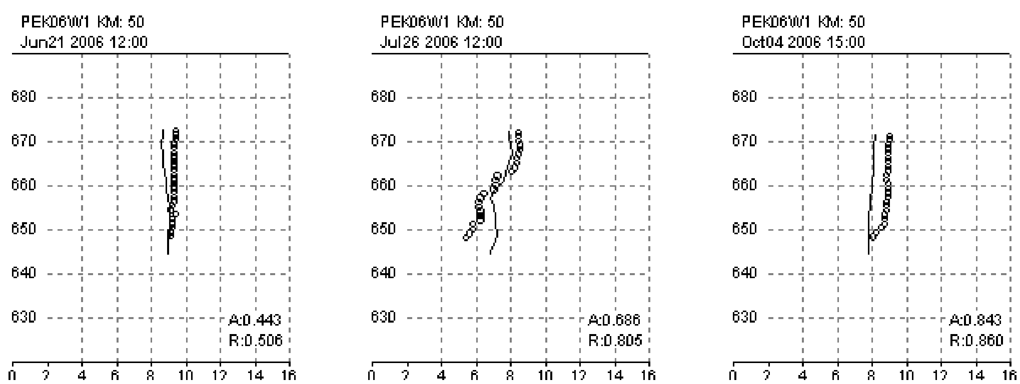


Figure 9-23. 2006 dissolved oxygen calibration at L4.

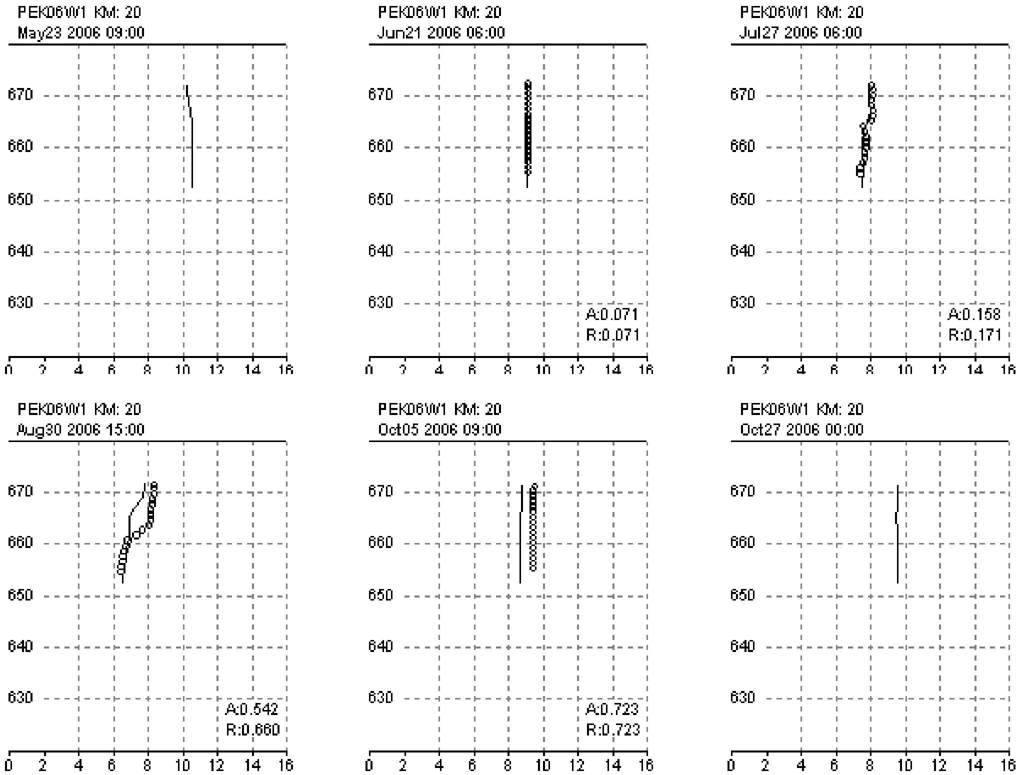


Figure 9-24. 2006 dissolved oxygen calibration at L6.

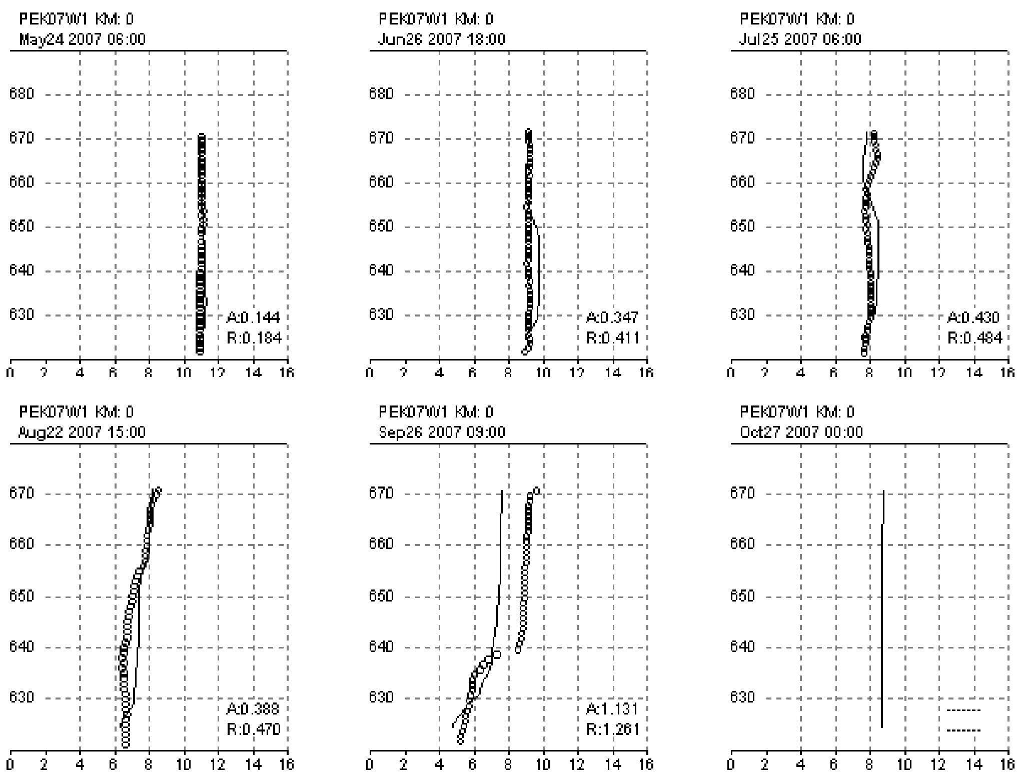
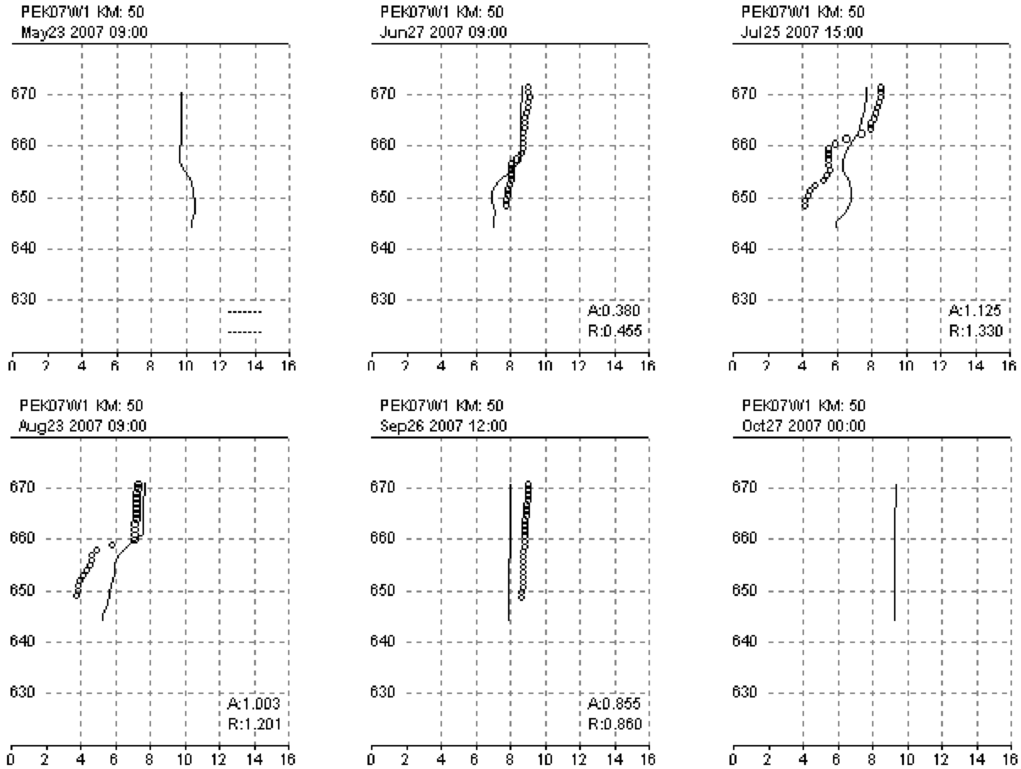


Figure 9-25. 2007 dissolved oxygen calibration at L1.



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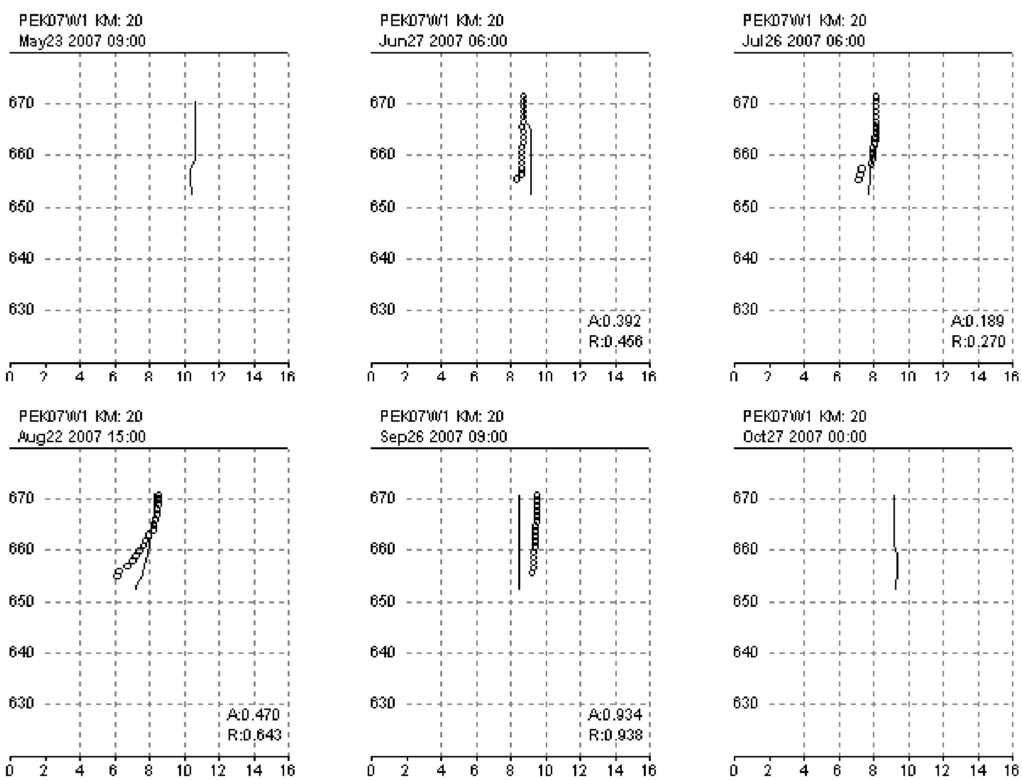

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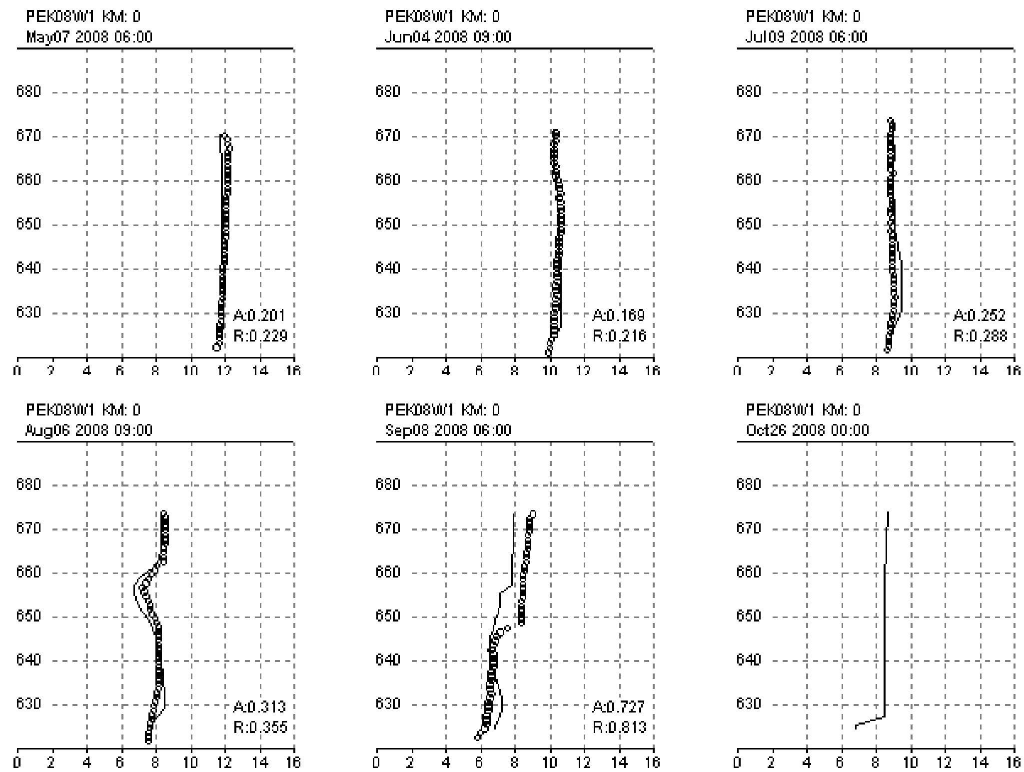
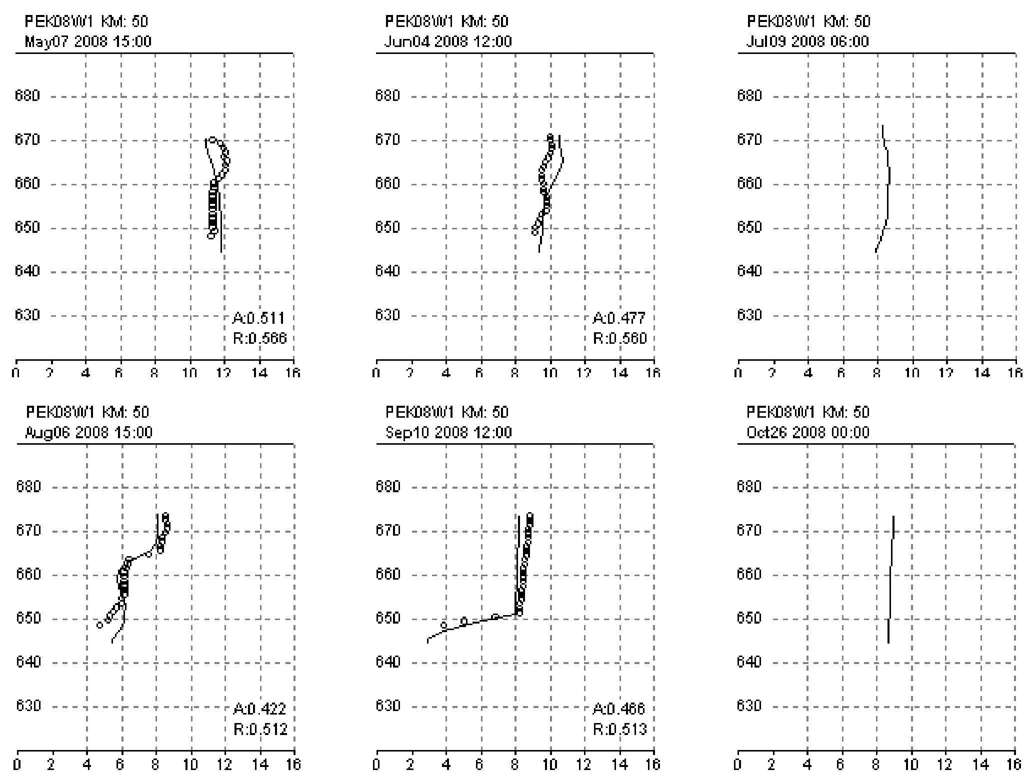


Figure 9-28. 2008 dissolved oxygen calibration at L1.



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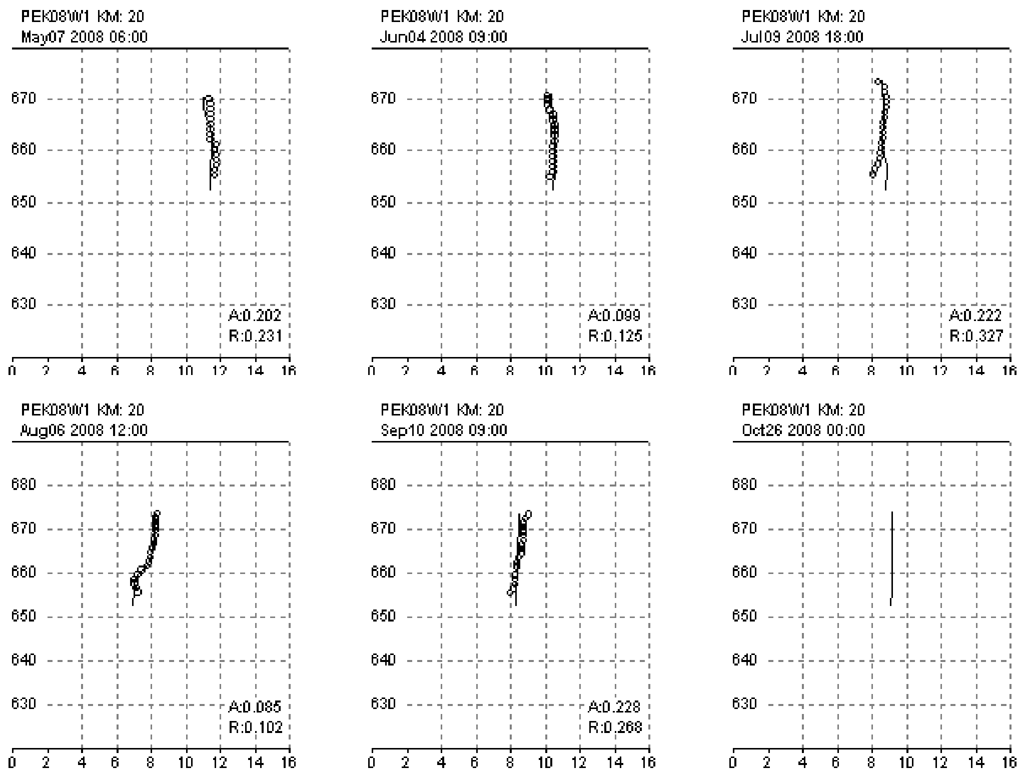

Figure 9-30. 2008 dissolved oxygen calibration at L6.